NOTES

ON THE

APPLICATIONS

OF

ELECTRICAL MACHINERY

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SPRING TERM, 1897.

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ELECTRICAL MACHINERY.

DIRECT CURRENT MOTORS.

1. **The Electric Motor** is a practical machine constructed and used for the transformation of electrical energy into mechanical energy. It is the necessary terminal apparatus where power is transmitted electrically. The principles of operation of the electric motor are in all cases those of the reversed dynamo. From this it does not follow that one will always obtain a satisfactory electric generator by driving backwards an excellent motor. In fact, excellent street railway, elevator and some shop driving motors when driven as generators, will give very unsatisfactory results. The reason for this is that motors are generally required for totally different classes of service from that required of dynamos. A generator is required without sparking at the commutator to furnish a variable current at constant E.M.F. or at an E.M.F. that slightly increases with the current. It is the duty of the electric motor, with reasonable freedom from sparking at the commutator, to furnish from a constant pressure circuit a variable mechanical torque at variable speed in some types and at constant speed in other types. The student will remember that many of the characteristic features of design of the dynamo had to be adopted because being driven at constant speed it must maintain at variable current output a definite terminal pressure. In practice the motor that is required to furnish a constant speed under varying mechanical load by taking current from a constant pressure circuit, is practically a reversed constant pressure generator. The far greater proportion of motors in practice are required to produce both variable torque and variable speed. These are used for driving street cars, and for operating hoists, elevators, etc. They are designed for a normal effort to rotation, speed and efficiency, and with conductors of such size that the motor shall not heat unduly during prolonged normal operation and that the commutator performance shall be satisfactory without shifting the brushes regardless of the direction of rotation of the armature. As a rule in this class of motors less attention is paid to the re-

duction of armature reaction. Sparking at the brushes is limited as much as possible by the use of symmetrical windings, a maximum number of commutator bars producing a commutator of ample proportions, and by the use of carbon brushes. The brushes may thus be set on the normal diameter of commutation and do not have to be changed with the load or direction of armature rotation. These motors carry more copper in proportion to iron than do the generators, and as a rule they are lighter and more compact than generators.

2. **The Transformation of Electrical into Mechanical Energy.** Any portion of an electric current through which current is established by an electric generator when placed in a magnetic field, is acted upon by a mechanical force that tends to move the circuit or conductor across or at right angles to the field. The relation of the directions of field induction, current and motion of the conductor is given in fig. 1. The direction of motion of the conductor will be reversed when either the field or the current are reversed; it will remain the same if both field and current are reversed. The actual value of the mechanical force exerted by the field on the conductor is $f = Bli \sin\theta$, where f is the force in dynes, B the induction in lines per sq. cm., l the length of the circuit located within the field, and i the current strength in c.g.s. units, while θ is the angle between the directions of the motion and of the field. The corresponding force in grammes per ampere is $f' = Blc \sin\theta \div (980 \times 10)$; for grammes per ampere per centimeter length, $f'' = Bc \sin\theta \div (980 \times 10)$; for pounds per ampere, $f''' = Bcl \sin\theta \div (980 \times 454 \times 10)$; and for pounds per ampere per foot, $f_1 = 30.5\, Bc \sin\theta \div (980 \times 454 \times 10)$. In all ordinary cases met with in practice, $\theta = 90^\circ$, $\sin\theta = 1$, so that this term is generally unity.

Whenever any portion of an electric circuit carrying current is located in a magnetic field and is made to move, an E.M.F. is generated, $E = (Blv \sin\theta) \div 10^8$. When the direction of motion is the same that the field would naturally give and as shown in fig. 1, the E.M.F. generated is opposed to the current and is opposite to the E.M.F. of the generator. The field under these circumstances assists the conductor to move by an amount of mechanical power equal to the amount of electrical energy removed from the electrical circuit. This amount of energy is equal to the product of the E.M.F. generated into the current in the circuit. Should the motion of the conductor be opposite to that which the field

would naturally produce, the E.M.F. generated by the motion of the conductor through the field will have the same direction as the current and the generator E.M.F. The field when the conductor moves thus assists the generator to establish the current. The amount of mechanical power absorbed by the field and conductor will be equal to the increase of electrical power in the circuit. The mechanical power, P, produced or absorbed by the circuit in the magnetic field equals in dyne-centimeters per second, $P = iBlv \sin\theta$; Watts $= W = P \div 10^7 =$ C.E.; $c = 10\,i$; $E = Blv \sin\theta \div 10^8$; $W = iBlv \sin\theta \div 10^7$ If the original of the prime mover is considered positive, the dynamo power will be negative and the motor power will be positive. It follows, therefore, that in any case where the field and current are each positive $\sin\theta$ will be positive for the motor and negative for the dynamo generator of E.M.F.

3. **The Practical Principles of Motor Construction.** The mechanical and electrical principles are applied for motors in much the same manner as for dynamo construction. The same variety of armature windings, mechanical details of armature core construction, methods of mounting and insulating armature and field conductors, commutator construction and of field forms that are applied for generators are applied also for motors. The proportions vary from those of dynamos according to the particular practice as explained in section 1. There are, therefore, motors with open and closed coil armatures, each with bi-polar or multipolar series or shunt fields. For operating these there are two general methods of electric power supply. By the one method the current in the circuit is kept constant as in arc lighting, the pressure varying with the power taken, and the motors with series fields are, therefore, put into the circuit in series, the current passing first through one and then another, etc., as in arc lighting. This is known as the constant current system. By the other method the parallel system of current distribution is adopted. A practically uniform pressure on the supply leads is maintained by the generator. From these leads the motors take current in parallel as in incandescent lighting, and the generator supplies current in proportion to the electric power demanded by the motors. Series and shunt motors alike are operated most extensively in practice by this system. This is known as the constant pressure system.

Open coil series motors have been tried in practice to a small

extent. They are inherently less adaptable to the demands of practice than the closed coil machines. These motors are adapted to work at constant current with the electrical pressure at the brushes varying as the lead varies. The requisite regulation is effected by varying the angle of lead of the brushes by hand or automatically by means of a centrifugal governor. There are so few of these motors in actual use at the present time that space cannot be given for their further discussion.

Closed coil constant current series motors are used occasionally to obtain power from arc lighting circuits. They give better practical results than the open coil type. The torque is varied to suit the demands of varying loads by either of two methods. One is by shifting the brushes, and this is the method more generally applied. The other is by varying the field turns. When the former method is used the motor is so designed that the magnetic difference of potential produced by the field between the pole faces is in excess of the armature m.m.f. by the amount which will establish an induction sufficient to commutate the armature current. Since the current is constant at all loads this relation is easily obtained in practice. As it holds for all diameters of commutation, it follows that sparkless commutation will be obtained with the brushes in any position. The torque is a maximum when the brushes are in the normal diameter of commutation and it is zero when at right angles to this diameter. When variation of speed at various torques is desired the brushes are shifted by hand. If the speed is to be maintained constant at all loads the brushes are shifted automatically by means of a centrifugal governor. When the method of varying the field turns is used for regulation, the field will vary from practically zero when the motor is running light to a maximum when fully loaded. The brushes are kept on the normal diameter at all times. To insure that commutation will occur under all variations of load without serious sparking, carbon brushes and a commutator ample in number of bars and dimensions must be employed. The regulation is done by hand or automatically as before, according as the speed is to be varied or maintained constant. These motors are employed practically where an arc light circuit furnishes the only available source of electrical energy, and then in sizes generally smaller than twenty-five horse-power. At the present day the constant current system is nowhere adopted as a standard method of power transmission. One serious objection to the system is due

to the high pressures that must be employed when the current is maintained constant at a small value. The high pressures that must be employed by the motor produce danger to life, increase the cost of attendance and repairs, and introduce added fire risk owing to the serious arcing that must occur when the electric circuit about the motor becomes impaired at any point or becomes partially opened.

Constant potential series motors are applied at the present time more extensively than any other type. This type is used for traction purposes, operating hoists, elevators, and generally for the supply of all sorts of services where the power demanded is intermittant and at all times irregular or unsteady. A series motor when operated from a constant potential circuit will naturally produce a different speed for each value of torque that it is required to produce. The speed is high when the torque is small, and low when the torque is great. Independently of this the speed at a given torque is increased when field turns are cut out, while on the insertion of resistance into the circuit of the motor the speed for a given torque is lessened. Thus any desired relation of torque and speed may be obtained within the limits of safe operation of the motor. A point of greatest practical importance lies in the fact that the armature and field coil always receive the same current. The armature reaction always tends to weaken the field. The evil effects of this are overcome in the series motor where the field excitation increases with the armature current thus fitting the motor for sudden overloads and irregular work. The armature of a motor connected to a supply line acts like a short circuit the moment that the field excitation is interrupted. The series motor construction avoids the possibility of the application of the line pressure without due field excitation.

The constant potential shunt motor next to the constant potential series motor is used most extensively in practice. It construction is the same as the shunt or compound dynamo. It is used quite largely for "stationary" power supply; that is, for driving shops or factories and for similar classes of service where constant speed is desired. Its behavior is quite exactly that of the shunt or compound constant potential dynamo.

4. **Theory of Motor Control.** Owing to the simplicity of control that is adopted for constant current motors and the fact that they are used to a very small extent in practice, the theory of their control will be discussed merely qualitatively, while the methods of control that are used in practice for the operation of the series and shunt constant potential motors will be analyzed more accurately. Those methods present a greater variety of control and the motors are used almost universally.

Control of Open and Closed Coil Constant Current Motors. In these motors all regulation is effected by changes in the armature torque. Thus a given amount of power is obtained at a given speed in this type of motor by adjusting either the position of the brushes or the magnitude of the field induction so as to obtain the corresponding torque. The torque of a given motor depends on the product of the field induction and the armature current. In any given motor the induction through the armature established by the field is limited to that amount which causes saturation, while the current is at all times invariable and fixed at a definite value. In this type then, the torque due to the maximum field induction, and constant line current is the highest possible mechanical effort to rotation obtainable. The demands of much practice are such that motors, for very short intervals of time, are required to produce torques that are many times in excess of the normal full load running torque. A duty of this sort is impossible with the constant current motor. To obtain such a duty would necessitate the construction of a motor field many times larger than that which is needed for average or normal operation. The constant potential motor has the same field induction limit; however, it may draw from the line, for short intervals of time, any amount of current and thus produce the necessary torque to overcome a momentarily large increase in the load. This is another important reason why the practical application of the constant current motor is so very limited. The constant current motor must be constructed so that the maximum torque that it can produce will exceed that which will be demanded of it in practice. As explained in section 3, the torque is varied in practice in each instance by one of two methods.

The first method is by shifting the brushes. This is the more commonly used method. As stated, all motors of the constant current type are of the series class. The field coils in series with the armature carry the main current. The number of turns in

these coils is such that the maximum obtainable induction through the armature is produced at all times. Then when the brushes are on the normal diameter of commutation, the motor produces its maximum torque measured in pounds at one foot radius. The product of this torque into 2π times the safe speed of the motor, divided by 33,000 will be the normal output of the motor in horse power. The corresponding electrical horse power input is $CE \div 746$, where C is the line current in amperes and E is the sum of the motor E.M.F., E_m, and the fall of potential through the motor due to its resistance, R, and the line current, C, and which, therefore, equals CR. Hence $E = E_m + CR$. The efficiency is the ratio of the output to the input horse-powers. The interval losses or wastes are of three classes just as in generators: C^2R, hysteresis and eddies, and friction. The input minus the output always equals the sum of these losses. For lower power outputs the torque must be lessened. This is done by shifting the brushes. The effect is to change the sign of the torque produced by a portion of the armature conductors, thus opposing the balance of the conductors and lessening the total torque. The number of opposing conductors will increase with the angle of displacement of the brushes until points are reached midway between those at which normal commutation occurs. At this point the number of opposing conductors equals the balance and the torque is, therefore, zero. Further shifting of the brushes will reverse the direction of rotation of the motor, attaining a maximum negative torque when the brushes again occupy the normal points of commutation in their reversed position. In lessening the torque by shifting the brushes the motor E.M.F., generally called by text writers the counter E.M.F., is lessened proportionally. The same conductors that have their torque reversed have the E.M.F.s that are developed by their motions, also reversed. This occurs because these conductors are made to move under opposite poles. For this reason as the torque is diminished, the field and speed remaining constant, the E.M.F. with which the motor opposes the current furnished by the generator diminishes a corresponding amount. It is seen that these conditions of operation involve no change in the adjustment of the motor when the load demands the same torque at a higher or lower speed. The motor will operate from zero to the maximum speed at which it may be safely operated without any change of adjustment at any torque for which it is set, should the load demand this uniform torque over such a range of speed.

The second method of control is by means of the change of field excitation. This method is used but very little in practice. The change in field excitation is produced generally by cutting sections of the field winding out or in. Sometimes it is done by shunting the current past the field coil by increasing or diminishing the amount of resistance put in parallel with the field winding. Thus by changing the field excitation from zero to a maximum the torque is made to change through a corresponding amount. Aside from this difference in the method of torque variation the behavior of this motor is the same as that described in connection with the method of torque variation by shifting the brushes.

Notation for the Discussion of Constant Potential Motor Control. E is the E.M.F. impressed at the terminals of the motor.

E_m is the motor E.M.F. or in volts, that pressure which is developed in opposition to the generator pressure by the motion through the field induction of the motor armature conductors.

C is the current in amperes through the motor armature.

c is the current in amperes through the motor shunt field.

R_a is the resistance in ohms of the motor armature.

R_f is the resistance in ohms of the motor series field coil.

R_s is the resistance in ohms of the motor shunt field coil.

R^1 is the resistance in ohms external to the shunt field.

R is the resistance in ohms external to a series motor.

R is also the resistance in ohms external to the armature circuit of a shunt motor.

Q is the torque or effort to mechanical rotation measured in lbs. at one foot radius.

n is the motor speed in r.p.m.

A constant potential series motor receiving electrical power from service mains in practice is illustrated by the diagram in Fig. 2. From the point c at the service mains the current is taken through the safety devices and switch and thence to the rheostat controller at *H*. From *H* the current passes through the controller and field coil to the switch *R.S.* and from there through the motor armature and finally it passes back to the other side of the service main at c^1 by way of the main line switch *D.P.* and the safety devices. As the connections of the controller indicate, its function is first on starting to limit to the amount of current necessary for the desired motor torque by inserting all or a portion of the resistance between the contact points from *O* to *F*. By putting the lever *H O* in contact with points on the controller beyond *F*, turns in

the field coil *F.C.* may be cut out. The following relations between current, torque and speed exist for this type of motor when a constant supply of pressure is maintained on the service connections $C\ C^1$. The fundamental characteristics of the motor are due to design and construction. These are the ampere-torque curve given as the unbroken line in Fig. 3 and the ampere-speed curve which is the unbroken line drawn in Fig. 4. The ampere-torque characteristic of Fig. 3 is predetermined for a given motor only through the processes applied in designing; and for a finished motor is determined by trial with the ammeter and prony brake. Whether the amature is or is not permitted to rotate the result will be practically the same. This ampere-torque characteristic is always determined by the use of the full number of field coil turns. The corresponding characteristics with portions of the field coil cut out are readily determined when the fundamental has once been obtained. The broken characteristic in Fig. 3 was determined in the following manner for a case in which one third of the field coils were cut out at the controller by manipulating the contact lever *H O*: With all of the field coils in circuit 30 amperes produced a torque of 122 lbs. Two thirds of this field coil when passing 30 amperes will produce the same armature field induction as two thirds of 30, or 20 amperes, through all of the field coil turns. Now 20 amperes through the whole coil produced a torque of 57 lbs.; 30 amperes in the presence of the same field induction will produce a torque $= 57 \times 30 \div 20 = 86$ lbs. thus locating, as indicated in the diagram, a point on the new ampere-torque characteristic. Other points were thus determined, enabling one to draw in the broken curve as the ampere-torque characteristic for one third of the field coil cut out. Other characteristics for more or less field coil turns cut out would be determined in the same manner. This process of determining secondary characteristics of this class from the primary or fundamental is given by the following reaction which always exists:

$$Q'' = \frac{Q'C}{nC}$$

where n is the fraction of field coil turns included in the motor circuit, Q' is the torque due to the current $n\,C$ on the fundamental characteristic, and Q'' is the desired torque produced by the current C and the changed number of field coil turns.

The ampere speed characteristic is deduced from the ampere torque characteristic, as follows:

Equating the mechanical and electrical powers

$$\text{H.P.} = \frac{2\pi Qn}{33{,}000} = \frac{CE_m}{746}.$$

$E_m = E - C(R + R_a + R_f)$. For the fundamental ampere-speed characteristic, $R = o$. Substituting and transposing,

$$n = \frac{33{,}000\,[CE - C^2(R_a + R_f)]}{746 \times 2\pi Q}.$$

For example, the resistance of the motor whose characteristic is given in Fig. 3, is $R_a + R_f = 1$ ohm. What speed will the motor make on a 500 volt circuit at a current of 30 amperes and a torque of 123 lbs.?

$$n = \frac{33{,}000\,[30 \times 500 - 30^2 \times 1]}{746 \times 2\pi \times 123} = 809 \text{ r.m.p.}$$

In the same manner speeds corresponding to other currents are determined by obtaining a sufficient number of points on the curve necessary for its complete location. Thus the unbroken curve in in the diagram of Fig. 4 was determined. The lower broken curve in the same diagram was determined in the same manner for the case where $R = 7$ ohms, or a total resistance of $R + R_a + R_f = 8.$ ohms in the motor circuit. This shows the control effect by inserting additional resistance to be the lowering of the motor speed. Thus by variation of R any desired change of speed for values below those of the fundamental ampere speed characteristic· may be obtained. As R is increased, the loss of the electrical energy, C^2R, is increased and the efficiency correspondingly lowered. In practice the use of resistance for regulating purposes is only momentary, chiefly in starting the motors. Where greater speed at given current with its corresponding torque is required, than that which the fundamental characteristic will furnish, it is obtained by cutting out a portion of the field coil turns thus lowering the armature field induction, motor E.M.F. and torque at a given current and speed. The upper broken curve in Fig. 4 is drawn through points determined from the broken ampere torque curve of Fig. 3. In this case one-third of the field coil turns were cut out. Thus it is seen that any value of speed may be obtained within the maximum speed limit that the motor will endure at any value of the current or torque by adjustments of the resistance and field coil turns in the motor circuit.

Under all conditions of operation the efficiency will be the ratio the output is to the input. Efficiency $= \dfrac{2\pi Qn}{33{,}000} \div \dfrac{CE}{746}$

The Constant Potential Shunt Motor for which a complete diagram is given in Fig. 5 has a behavior that is so nearly like that of the reversed shunt constant potential dynamo that a study of that dynamo leads to an understanding of this motor. The main field exciting m.m.f. is derived from a field coil of many turns of fine wire shunted across the terminals of the motor and taking a small current, the value of which may be adjusted at the rheostat R^1. Current is admitted through the safety devices and switch, then first to the shunt field coil. After the field is established the armature current is established first through resistance by means of the contact lever of the controller at *V*. Armature current is thus in sufficient amount admitted to start the motor light or under load as the case may be. As the motor comes to speed the motor E.M.F., E_m limits the current and the resistance R may gradually be all cut out. The small series coil *S.F.C.* is not always applied. Many shunt motors perform their duty without the aid of this series coil. Its purpose is to weaken or strengthen the field set up by the shunt coil as the load increases, for the purpose of maintaining either constant or lessening speed with such increase of load. The range over which the field induction of a shunt motor is applied in practice is such as not to exceed the point of saturation. The induction through the armature may be taken as being proportional to the field exciting ampere turns. The relation between the speed and load currents of a shunt motor operated from a constant potential circuit is as follows:

$$\frac{2\pi n Q}{33000} = E_m C \div 746. \quad E_m = E - C(R_a + R_f)$$

$$K = E \div \text{normal motor speed.}$$

$$E_m = Kn.$$

From this it is seen that the value of E_m is fixed for each value of armature current, and that if n is to be maintained constant K must vary with E_m. As E_m diminishes with the load current by an amount, $C(R_a + R_f)$, it follows that for constant speed K must be diminished with the load in the same proportion as E_m.

$Kn = E_m = Bvl \div 10^8$, K can only be diminished with the load by causing the load current in passing through an opposing series field coil to diminish the armature induction, B, in the ratio $E_m \div E$. It was found in connection with the shunt constant potential dynamo that the armature reaction caused the induction B to diminish with the load current. This same result occurs in a motor and

the amount of diminution of the armature induction from this cause is frequently sufficient to cause the speed (n) to remain constant at all loads without the use of series turns whose m.m.f. opposes the shunt ampere turns.

Occasionally in practice series field turns are applied so as to assist the shunt turns. This is done so as to increase B as C increases, thus causing the speed n to drop off proportionally. This behavior is often desirable where the motor must handle very sudden changes of load occurring through wide ranges.

5. *The Series Motor in Practice.* As above stated, this type of motor is used for a variety of irregular kinds of work. It is used to drive street cars, hoists, elevators, and for many special duties. When properly installed the lead wires from the service connections before entering the building or structure where the motor is located, pass through impedance coils $L\,L'$, Fig. 3. On both sides of these impedance coils, lightning arresters are connected and furnished with a good ground connection G. Only the inside set of arresters is shown in Fig. 3. The connecting wires are then taken into the building and through safety fuse cut-outs for the purpose of cutting off the service connection should the current for any reason become excessive. The conductors continue through a double pole main line switch to be used for breaking the motor connections completely from the supply lines; then one side of the circuit passes through a double pole armature reversing switch and through the armature, then through the field and finally out through the controller to the other side of the main switch. All safety or manipulating appliances are mounted on slate, porcelain or marble insulating and fire proof bases. Great care is taken in manipulating the circuits of a motor so as not to form short circuits or destructive arcs that might cause serious fire risks.

Fig. 7 gives a diagram of a series motor in which a magnet in series with the motor operates a rheostat for automatic control of the current in elevator work and, therefore, to control the mechanical effort with which the elevator is driven when coming to speed from a full stop.

6. *The Shunt Constant Potential Motor in Practice.* In installing and operating a shunt motor it is necessary to apply the same character of safety devices and manipulating apparatus as were described above for the series motor. The controller omits the series field commutating points and in connection with it, the motor

is provided with an additional safety device. The purpose of this device is to open the armature circuit should the electric service be momentarily discontinued, as is often the case in practice. The stoppage of the supply pressure causes the magnet *M* in Fig. 5, which is connected in series with the field circuit, to release the contact lever which, actuated by a spring, is promptly returned to the position occupied prior to starting. Without this device the armature, standing still, would be connected across the supply mains when the pressure would again be applied. The supply line would at once be short circuited through the armature as it would be developing no motor E. M. F., and would be in circuit with no resistance, and there would be nothing but the safety fuses, therefore, to limit the current from attaining dangerous proportions.

Fig. 6 gives a diagram of a shunt motor circuit where the motor is applied to elevator driving. Here the magnet *M*, operating the controlling rheostat is wound with fine wire and connected across the brushes of the motor. This magnet receives current, therefore, in proportion to the motor E. M. F., and cuts out resistance in the armature in the same proportion, so that when the motor is operating at full speed the motor E. M. F. alone acts in limiting the armature current to that amount which is necessary to carry the applied load.

ELECTRICAL MACHINERY.

PLATE I.

Fig. 1.

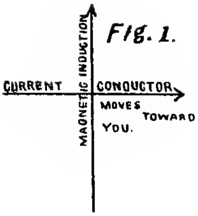


Fig. 2.

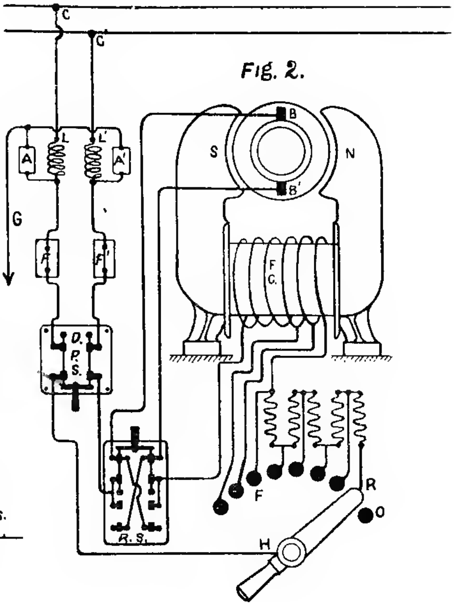


Fig. 3.

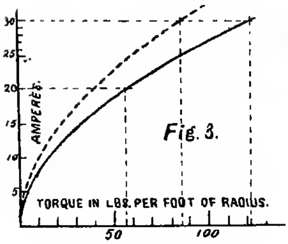


Fig. 4.

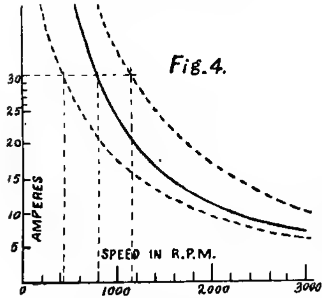


Fig. 5.

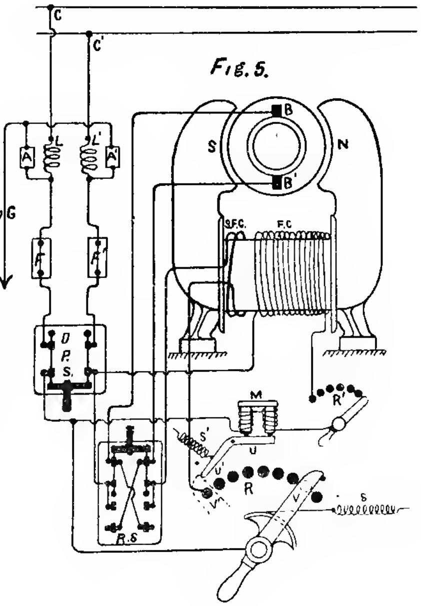


Fig. 6.

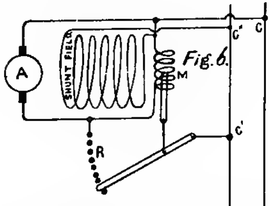
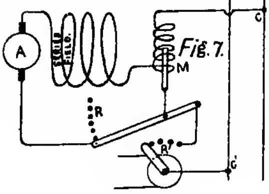


Fig. 7.



THE STORAGE BATTERY.

7. *The electric accumulator* is composed of two sets of plates immersed in a liquid which acts upon one of them more than on the other. In this respect it is exactly like the primary cell, from which it differs only in the fact that the plates are "formed" by the electrolytic action of the current used in charging it. An electro-motive force is always produced when one plate of a voltaic cell is acted upon more than the other, and in the primary cell, the plates are of different metals. In the secondary cell or accumulator, the plates are usually of the same metal, but in different chemical states, so that the action of the electrolyte is the same as in the primary cell. For example, in the lead accumulator, the positive plate is lead per-oxid and the negative plate spongy lead when the cell is fully "charged."

8. *The lead accumulator* is the one which is mainly used at the present time. It consists of two sets of "grids" (see fig. 1) made of antimonious lead, the interstices being originally filled with paste of litharge (red lead), which is afterward changed by electrolysis to per-oxid in the positive plate and spongy lead in the negative. The average electromotive force of the cell is two volts, and its capacity depends on the amount of "active material" present. The accumulator does not store energy in the form of an electrical charge, but the energy is used in changing the chemical composition of the plates and is restored to the circuit by the chemical affinity between the elements of the cell. When a number of accumulators are connected together, either in series or parallel, or both, they are called a "storage battery."

9. **Characteristic Behavior of Storage Batteries.** When in normal working order the average discharge voltage of an accumulator is two volts. When full it is higher, and when nearly empty it is as low as 1.8 volts. After this point is reached the falling off is very rapid and the cell is apt to be injured by the sulfating of the plates. For this reason the electromotive force of an accumulator is never allowed to fall below 1.8 volts. A much higher electromotive force is required to charge a cell than can be taken from it, for the reason that the cell has some resistance. This causes a "drop" in the electromotive force both in

charging and discharging. At least 2.3 volts are required to charge a lead cell and often much more, the exact amount depending on the value of the charging current. Fig. 3 shows curves of charge and discharge electromotive forces for a lead cell. From the fact that when the cell is discharged, both plates are sulfated, it follows that in this state the electrolyte (sulfuric acid, sp. gr. 1.2) is weaker than when the cell is charged. When a cell is fully charged the energy of the current is used in decomposing the electrolyte, which is given off in the form of gases.

Accumulator troubles. A cell is often short-circuited by paste plugs falling between the plates. This is frequently accompanied by warping or "buckling" of the plates, due to the unequal electrolytic action on the two sides. To remedy these difficulties the cell should be kept clean, and if the plates buckle they should be hammered flat between two boards. An important disease of lead plates is known as "sulfating." It is the formation of a hard layer of white sulfate on the surface of the plates, which insulates them from the electrolyte, making a high resistance and reducing the capacity. Sulfating is usually due to allowing the electromotive force of the cell to fall below 1.8 volts, which may occur if the cell be left uncharged for any length of time, for the leakage current soon empties the cell.

10. **Applications of the Storage Battery.** The commercial uses to which the accumulator may be put, are: (1) Traction purposes; (2) Isolated work of small extent; (3) In connection with central stations.

Storage Battery Traction. Up to the present time the accumulator has not proved itself well adapted to traction purposes for the following reasons: (1) Its lack of durability under the shocks of ordinary traffic; (2) Its great weight compared with the work to be done; (3) Its cost; (4) Inconvenience in handling; (5) The care and expense of its maintainance. Of these troubles, all but the first one have been to some extent overcome. by proper engineering, but up to the present time a cell has not appeared which will endure the shocks of ordinary traffic for more than a few months. All the cells on the market have been repeatedly experimented with for traction purposes, but all have been abandoned after a fair trial. These failures do not, however, prove the undesirability of the storage battery for traction purposes, for the independent unit is the ideal system of traction. The custom, in the cases in which the experiment has been tried

is to place from 96 to 150 cells under the seats of the cars, or in a special receptacle in the truck, and to change these few every few trips, the extra cells in the meantime being charged and ready for the car on its return. By means of suitable machinery, the time required for changing the cells has been reduced to less than one minute, and the operation is, to a large extent, automatic.

Isolated work. There are many cases in which a small amount of power is desired at a distance from an electric circuit, and in cases of this description the accumulator has a large field. For launches, train lighting, small motors and such work the accumulator, in many instances, proves to be a convenient and economical secondary source of power.

Application to central stations. The great field for the accumulator at the present time is in connection with central stations. The importance of their use has long been known in Europe and at present 80 per cent. of the stations in Germany and Austria are supplied with one or more batteries of accumulators. The important stations in this country are also adopting the accumulator as an auxiliary device. The uses to which the battery may be put in a central station may be summarized as follows: (1) To straighten out the load curve; (2) to keep up the voltage on heavy load; (3) to carry the entire load at times when it is minimum; (4) to unify the engine load; (5) to act as a regulator of voltage; (6) for use in sub-stations; (7) for the transformation and subdivision of voltage. These topics will be considered in detail.

To straighten out the load curve. A curve of the load of a central station, plotted for twenty-four hours, (see Fig. 2) will show that at certain hours a greater expenditure of power is required than at others, and much greater than the average. This maximum may be double the average load, but it only lasts for a couple of hours. It necessitates, however, an engine power sufficient to supply the maximum load, and with the engine must be furnished dynamos, boilers and corresponding accessories. This surplus engine power remains idle for the greater part of the day and thus represents a waste of capital invested. . The function of the accumulator in this connection is to receive a charge during some part of the day, and when the extra load, or "peak" comes on, to assist the engines by discharging into the line. In this way the extra equipment is rendered unnecessary and economy is secured.

To keep up the voltage on heavy load. At some distance from the generators, a heavy load will often cause a considerable drop in the voltage, on account of the resistance in the line. The electromotive force of the generator cannot be raised to any extent, on account of injury to incandescent lamps and apparatus near it. Suppose a storage battery to be placed at the end of the line furthest from the generator, which at light loads will receive a charge, but which when the voltage drops owing to the resistance of the line, will furnish current to the line and thus obviate the necessity of raising the voltage of the generator. A common example of this kind of practice is as follows: It may be desirable to extend a line beyond its original limits, in which case a new line, or its equivalent, will be required from the extension back to the generator. If, however, a battery be placed at the beginning of the extension, it may be charged in the hours of light load on the existing wires, and discharged as required, and there will be no need for additional copper back to the generator.

To carry the entire load when it is minimum. At certain hours during the day or night, the load on the engines is very light and they are run at considerable disadvantage, the same amount of attendance being required. If, during the time of heavier load a battery be charged, it may be discharged into the line at the time of light load and the machinery may be shut down, with the consequent saving for attendance.

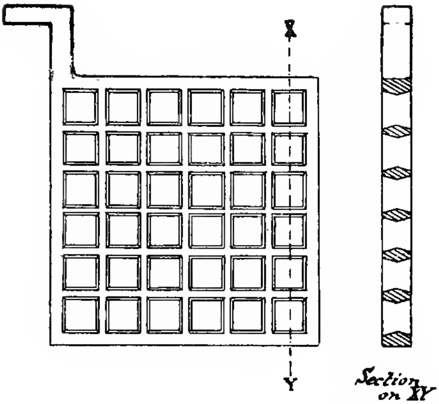
To unify the engine load. The great variations which occur in the load of an engine lower very much its average efficiency of operation. A steam engine works most efficiently at, or near, its normal load; but in a station, especially a power plant, the load fluctuates rapidly and between wide limits. The accumulator, if so arranged as to be charged when the load is light and discharged when the demand for current is heavy, will render the engine load uniform, and this can be arranged so that the engine will always be running at maximum efficiency. Similar reasoning applies to the construction of the line. Suppose that the power to be delivered at a certain point, distant from the station, fluctuates between wide limits. Evidently the line must be of capacity sufficient to supply the maximum power demanded. An accumulator placed at, or near, the point of demand of the power, may be charged when the load is light and discharged when it is heavy and the current carried by the line from the station may thus be kept constant, which will give the condition for the maximum economy of line as well as engine.

To act as a regulator of voltage. In certain prime movers, such as the gas engine, the supply of power is apt to be irregular, and for this reason cannot be applied to uses where a steady electro-motive force is required ; *e. g.*, electric incandescent lighting. In this case an accumulator, placed across the terminals of the dynamo, acts to steady the electro-motive force by taking a charge when the electro-motive force is high and restoring it when the electro-motive force drops below the normal value.

For use in sub-stations. A common practice in some places is to charge a number of batteries of accumulators in series, these being located at certain centers from which the current can be economically distributed. In this way the charging current is small and a small wire may be used for carrying it.

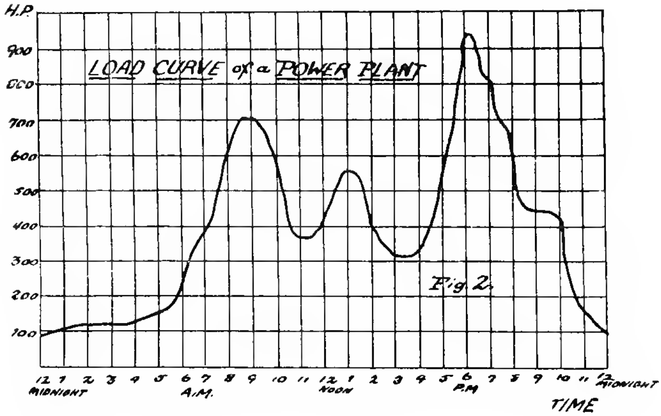
For the transformation and sub-division of voltage. Finally, accumulators may be used for the transformation and sub-division of voltage. The first is accomplished by charging the batteries in series and discharging in smaller batteries either in parallel or separate. Or the opposite process may be used to raise the available voltage by charging in parallel and discharging in series. For sub-dividing the voltage, the cells are charged in series and the series may be tapped at such points as to give the voltage required, each cell furnishing two volts. In this way the three or the five wire system of distribution may be used from one generator. By placing a battery across the terminals of a 220 volt dynamo and connecting the neutral wire to the central part of the battery, the Edison system may be used.

PLATE II.



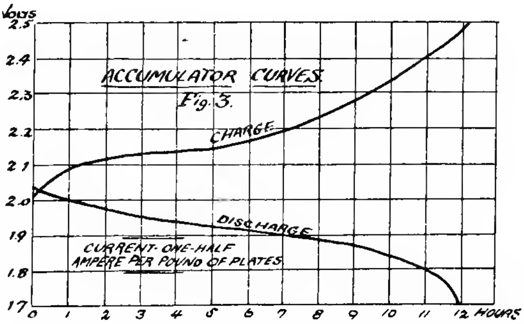
Accumulator Plate.

Fig. 1.



LOAD CURVE of a POWER PLANT

Fig. 2.



ACCUMULATOR CURVES.

Fig. 3.

LINE EFFICIENCY AND COPPER ECONOMY.

11. The problem of the transmission of electrical energy with commercial economy divides itself into several phases, namely: (1) The transmission of a given amount of power a certain distance with a fixed loss; (2) the transmission of a given current a certain distance; (3) the distance to which a given power can be transmitted. All of these items are to be calculated for maximum commercial efficiency.

Line efficiency is the ratio of the power delivered by a line to that which it receives. Evidently, the more copper a line contains the more electrically efficient will it be. Also any improvement in the quality of the copper or other material used, will have its effect upon the efficiency. A line may, however, be electrically efficient and yet not be commercially so, for the cost of the extra copper may be greater than the saving in power would warrant.

12. Problem 1. **To transmit a given amount of power at a fixed loss over a given distance with maximum economy** will necessitate the employment of a high voltage. In this case the electrical efficiency of the line is given. A high voltage is more economical than a low one, because the current decreases at the same rate at which the voltage rises, with the same amount of power delivered. With a smaller current a smaller wire may be used with the same line loss. As the power lost in the line is equal to the product of the square of the current by the resistance, the size of wire will vary directly as the square of the change in current or inversely as the square of the change in the voltage. For example, if a given line would transmit 100 H.P. at 10,000 volts with a weight of 1,000 pounds, an increase in the voltage to 20,000 volts would reduce the weight of wire needed to $1000 \div 2^2 = 250$ pounds.

The limit to which the voltage may be raised without danger to apparatus is the determining factor in this case. It is expensive to insulate a dynamo and line for excessively high pressures, and finally a point will be reached at which the saving in copper from an increased voltage will be more than counterbalanced by the expense and difficulty of insulation. In alternating current systems, pressures of as high as 30,000 volts have been used successfully, but expensive insulators are needed to prevent leakage of the current from line to line or from the line to earth.

13. Problem 2. **To determine the most economical size of wire to carry a given current a certain distance.** This is an entirely different problem from the preceding, for, as the current is fixed in value, the loss will vary directly as the resistance. As the size of the wire is increased its cost is also increased at the same rate, while the energy lost is less with a larger wire. There must be some point at which the increased cost for copper is no longer counterbalanced by the money value of the power saved.

Kelvin's Law. Lord Kelvin stated this principle about as follows: *The proper size for a wire which is to transmit a given current will be such that the interest on the investment in the line, and accessories which vary with the size of the line, will be equal to the annual money value of the loss of electrical power.* This law is almost self-evident, for if the saving does not compensate for the expenditure it is evidently a poor investment, and on the other hand, if an increase in the line would more than pay interest on the investment, it would have to be increased in order to have an economical line. This law is graphically shown in Fig. 1, which is the method for solving this kind of problem. The curves there given illustrate the following problem:

Example. With copper at 14 cents per pound and electrical energy worth 7 cents per kilo-watt-hour, and money at five per cent. per annum, *what size of wire should be used to transmit 10 amperes* a distance of 1000 feet? In solving this problem the interest on the cost of the wire and the annual value of the loss in power are plotted as ordinates while the sizes of wire are the abscissae. In calculating the kilo-watt-hours for a year the assumption is here made that the current flows for 3000 hours per year. It would, of course, vary with circumstances. The cost of insulators, etc., has been neglected, although that would often be taken into account when they vary in size with the size of the wire. In the problem we find that the curves cross each other at No. 0 wire, Brown and Sharp gauge. The total cost of delivering the power at one end of the line after it has been received at the other will be given by the sum of the ordinates of the two curves at any point, and this forms a third curve which shows the cost of using the line with the different sizes of wire. This curve has its minimum value where the other two curves cross.

Houston and Kennelly have shown that, after the size of wire has been determined for one current, the proper size for another current may be found by simple proportion. That is, if a wire of

one-tenth of a square inch section would carry a certain current at maximum commercial efficiency, one of two-tenths of a square inch section would carry twice the current with the same efficiency. This is evident because the cost of copper due to the added current and the loss in the line due to the same current have been increased in the same proportion.

14. Problem 3. **To determine to what distance a current can be transmitted economically.** The question to be determined in a case of this kind is whether the power can be delivered from the end of the transmission line cheaper than it could be generated on the spot, taking into account the cost of copper in the line. Here the matter of allowable voltage becomes prominent, for, as has already been seen, the cost for copper diminishes very rapidly as the voltage rises. The first point to be settled is the highest practically obtainable voltage. Having determined this and the amount of power which is to be delivered, Kelvin's law will give the proper size of wire to use for any particular distance. A number of such distances can be calculated in this way. *The point at which the interest on the cost of the line is equal to the annual money difference between the values of power at the two ends of the line is the maximum distance to which the power can be transmitted commercially.* A transmission line would only be put in where there was a considerable difference between these two costs. As an example, take the Niagara Falls and Buffalo transmission. Power can be generated cheaply at the Falls, while to produce electrical power by steam engines is more expensive at Buffalo. It is found that even with the great cost of the transmission line, the power can be sold at a profit in Buffalo, cheaper than would be possible by steam generation on the spot. It is an open question, however, with the voltages at present obtainable, whether the same power could be transmitted as far as New York at a price which would compete with steam power.

All of the foregoing conclusions apply mainly to a power transmission line. Incandescent lighting circuits present a different problem, for in this case a certain drop in the voltage is always specified, and with a certain drop and a given current the size of wire is determined without much calculation.

DIRECT CURRENT SYSTEMS OF DISTRIBUTION.

The earliest and simplest method of connecting electrical apparatus with the generator consisted in running a pair of wires from the terminals of one to those of the other. It is usual to have more than one piece of apparatus connected to the same generator, and in this case certain modifications of the simple transmission line are introduced in order to obtain the greatest economy of distribution. There are two main classes of apparatus to which direct currents are furnished, namely; machines arranged for a constant current and those adapted to the use of a constant pressure or difference of potential.

Constant current apparatus is always connected in series, for as the function of the generator is to keep the current constant, each piece of apparatus must be in such connection with the generator that the latter may have control of the current. The employment of a high potential is thus rendered necessary and a given amount of energy may be transmitted with a smaller current than would be required with a lower electro-motive force. This form of transmission, that is, connection of apparatus in series, is economical of copper and energy loss, for the wire is much smaller than for constant potential work, and the loss in power is proportional to the square of the current if the resistance is uniform. Arc lamps are usually connected together in series in this way, (see fig. 2) about fifty volts being allowed for each lamp in the series, with a current of ten amperes. Sometimes incandescent lamps are also connected in series, but the system is objectionable from the fact that the burning out of one lamp in the series, extinguishes all the others at the same time. Arc lamps are so arranged that when the arc is broken the lamp automatically short-circuits itself.

Constant potential apparatus comprises the large part of electrical machinery and a different system of transmission is required. Each piece of apparatus must be in separate connection with the generator in order that it may receive the full electro-motive force. Two wires are run from the generator, usually known as "mains", between which the difference of potential is practically constant at all points. The apparatus is connected to these mains in "parallel", that is, the terminals of each piece of apparatus are connected to the wires independently of the other pieces. (See fig. 3.)

The plain **two-wire system** has the disadvantage that, owing to the resistance of the mains, the difference of potential at the end of the line furthest from the generator is less than that at the near end. Apparatus which is sensitive to small changes in the voltage, such as incandescent lamps, will not operate satisfactorily unless the mains are made of such size that the "drop" is inappreciable. To do this requires a large amount of copper, and various expedients have been tried in order to save copper in the line, while keeping the difference of potential between the mains fairly constant. It should be said, however, that the simple two-wire system is in very general use, for circuits of reasonable length, and with satisfactory results.

Expedients for saving copper in two-wire transmission. The simplest method to obtain a uniform pressure at all points of the line is what is known as a "loop" distribution, (see Fig. 4). One main is connected in the ordinary way to the dynamo, while the second dynamo terminal is attached to the far end of the second main by a separate wire, or loop. In this way each lamp on a lighting circuit is subjected to the same pressure, but it depends on other circumstances, whether the amount of copper in the loop, if used in the simple system, would not produce nearly the same results. If both the beginning and the end of the pair of mains are near the dynamo, as in figure 5, the method is an economical one. Although theoretically nearly perfect this system will only apply in a simple circuit.

In a large lighting system, the lamps are very seldom connected directly to the mains, but to branches, as shown in figure 5. There are also a number of mains carried from the dynamos in different directions. Now if the mains be cross-connected at the points where they approach each other, the difference of potential between the wires will be equalizad, to some extent. This forms what is known as a "net-work" of mains, and it is the universal custom in locations where the cross-connection can be conveniently made. Before leaving the two-wire system it must be noted that this system can only be economically used where the load is not very far from the generator, except a high potential be used. In street railway work the pressure is high, and a perfect uniformity of pressure is not necessary, so that the two-wire system is used in this case. The trolley wire and feeders form one main and the track and ground form the other.

The three-wire system. It is evident that the higher the pressure used in distributing current, the smaller will be the re-

quired size of the wires. Edison has taken advantage of this fact by using two dynamos in series, furnishing a total of 220 volts. The lamps are connected in series of two by connecting one terminal of each lamp to an outside wire and the other to a smaller wire which runs to the connection between the two dynamos (fig. 6). This inner wire is known as the "neutral" and its office is to carry back to the dynamos the excess of current in one branch over that in the other. When both branches are balanced, that is having the same number of lights on each, the neutral carries no current. The neutral wire is made of one-half the cross sectional area of the other wires. The use of the system results in a large saving of copper, in the proportion of two and three-fourths to four, as compared with the use of two distinct circuits. In spite of this great saving in copper the economical commercial use of the Edison system is limited to short distances, say one-half mile, and it is thus only adapted to lighting in the densely populated sections of large cities. The three wires which are used for the mains are encased in the same tube of iron, from which they are insulated by rope and pitch. In the houses the wires are run either in tubes in the wall, or on porcelain knobs, which raise the wire clear of the wall.

Leonard Three-wire System. This is a modification of Edison's plan. (See fig. 7.) A single dynamo supplies the outside wires with a pressure of 220 volts. The neutral is used as before, but it is connected at one end to the terminals of a small auxiliary dynamo which is belted to the large generator. As before, one end of the neutral is open. When the system is balanced the neutral carries no current and the auxiliary dynamo gives none, for it is adjusted so that this will be the case. If the pressure on the branch, to which the small dynamo is connected, falls, due to the pressure of more lamps on that side,-the auxiliary dynamo will assist the main generator in supplying current to that branch. If, on the other hand, the pressure on this branch rises, owing to the other branch carrying more than its share of the load, the auxiliary machine runs as a motor, thus assisting the generator, and at the same time balancing the two branches by taking current when its branch is underloaded and by supplying current when it is overloaded.

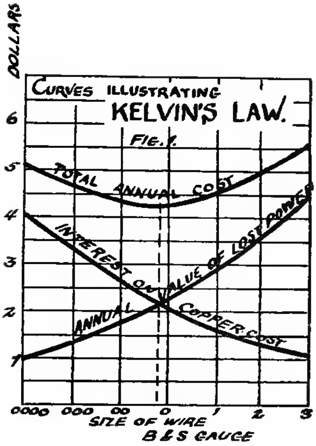
Five-wire Siemens-Halske System. Siemens improved the system of Edison by using four wires instead of three with a proportionate saving in copper. This was afterward extended to the use of five wires, for various reasons. Five hundred volts are

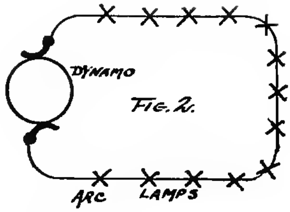
used between the extreme wires and this voltage is convenient for the following reasons: (1) The same dynamo may be used for the running of eight arc lamps in series; (2) the same dynamo may be used for running street railway cars; (3) the saving in copper due to the high voltage; (4) the use of motors on the lines, which run efficiently at this voltage. As the use of a number of dynamos in series would be inconvenient, a different device has been adopted. As shown in fig. 8, a single dynamo, which furnishes 500 volts to the mains, is allowed to drive a motor which has four armatures connected in series and revolving in the same magnetic field. These armatures are known as the "equalizers"; and they are located in sub-stations near the point at which the load is located, so that but two wires are required to be run from the generator to the sub-stations. The neutral wires, of which there are three in this system, are connected to the junctions of the equalizer armatures and they carry current back to the armatures when any of the branches become unbalanced. The function of the equalizers is to keep the pressure on the various branches at the same value, 125 volts, and it is accomplished as follows: If the electro-motive force in a branch falls below 125 volts, as would be the case when one branch was taking more current than the others, the corresponding equalizer armature would act as a dynamo and make up the deficiency in the current. On the other hand, if a branch took less current than the others, its electro-motive force would be high and the equalizer armature would take current from this branch and would run as a motor. In this way the electro-motive force of the various branches is kept uniform. The system has some disadvantages owing to the presence of the equalizers, which require some attention and which must be brought up to speed if the main circuit is broken for any reason.

Both the three and five-wire systems can be connected to form a net-work as in the simple two-wire system and thus produce an equalization of pressure in the mains.

Combined systems. Combined series and parallel systems are sometimes employed, *e.g.*, when two arc lamps are run in series across 110 volt incandescent light mains. Or a number of incandescent lamps are run in series across a power circuit of 500 volts. If it is desired to run a large number of lamps under the latter system, the current must be switched into a resistance if one lamp is to be extinguished, or the current will be cut off from the whole series. This latter method is not in general use.

PLATE III.





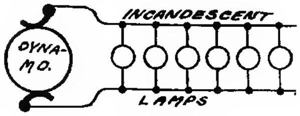


FIG. 3.

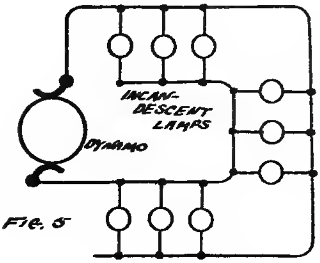
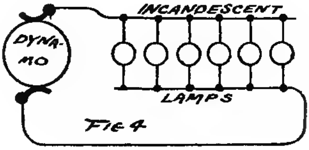


FIG. 5



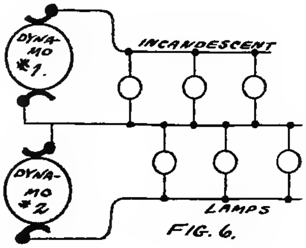
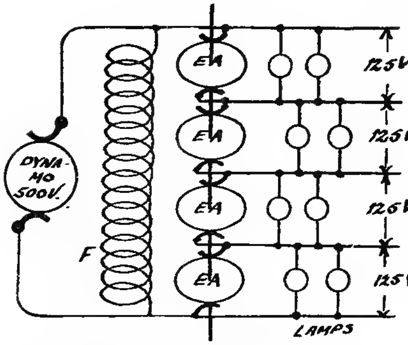
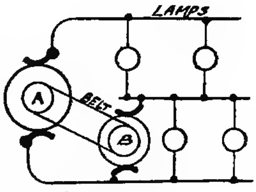


FIG. 6.



F = COMMON EQUALIZER FIELD
EA = EQUALIZER ARMATURES.

FIG. 8



A = MAIN DYNAMO
B = AUXILIARY DYNAMO

FIG. 7.

CALCULATION OF INCANDESCENT LIGHT WIRING.

Incandescent lamps are not usually connected directly to the mains, except in small installations, but to branches connected to the mains at different points. In cases of this kind, the mains and branches will be of different sizes and must be calculated separately.

Wiring Calculations. The specifications for an incandescent lighting system always call for the delivery of a given current at the lamps with a certain "drop" in the pressure in the line. This drop must not be very great, for the voltage at the lamps varies by the amount of the drop, when lamps are turned on or off. If but few lamps are in circuit, the drop is slight and the lamps have nearly the voltage of the generator. When all the lamps are connected the resistance of the line causes more volts to be lost in it.

As a difference of a few volts is noticeable in an incandescent lamp, it is evident that those near the generator would burn brighter than the distant ones, if some precaution were not taken to prevent it. By the use of lamps of a higher resistance near the generator this trouble may be overcome, but the method is not used much as the lamps are apt to become mixed.

As previously stated, a certain drop in the line is always allowed from generator to lamp, and this may be as much as two volts on a 110 volt circuit and correspondingly smaller on a 50 volt circuit. To calculate the proper size of wire to cause this drop is the problem now in hand. There are two separate cases which are likely to be met, namely: (1) A number of lamps distributed along the mains; (2) A number of groups of lamps on different branches. Another case which might occur would be that of a net-work of mains and branches, but this is only a difficult application of the principles which will be here laid down for the simpler cases.

Case 1. (See fig. 1). A certain drop in voltage is allowed between the generator and the extreme lamp, at which point the voltage will be lowest. The current gradually drops off as lamp after lamp is passed, and if the same size of wire is used throughout, as is usual with a small circuit, the drop also becomes less per unit length as the end of the line is approached. This can be

seen by reference to the figure, for from the generator to *b* the current as well as the drop is maximum, and the drop is less with a smaller current, the resistance per unit length being uniform. The line must be divided into sections in which the current is uniform and the drop calculated separately for each section. The total drop will be the sum of the "drops" in the separate sections.

Example:

A circuit of 200 feet length contains eight lamps twenty-five feet apart, as shown in figure 1. The dynamo supplies 112 volts and a drop of two volts at the extreme lamp is specified when all the lamps are on. If each lamp takes one-half ampere, what size of wire should be used? Refer to the wire table on page 28.

The drop in each section is the product of the current by the resistance of the section. Let ω be the resistance of the unknown wire per thousand feet. Then the drop per section will be:

$$\begin{matrix}\text{Number}\\ \text{of lamps}\end{matrix} \times \begin{matrix}\text{current}\\ \text{per lamp}\end{matrix} \times \left(\begin{matrix}\text{length}\\ \text{of wire}\end{matrix} \div 1000\right) \times \omega.$$

Substituting values for each section,

Drop from	$a - b$	.2	ω
	$b - c$	.175	ω
	$c - d$	.150	ω
	$d - e$	.125	ω
	$e - f$	.100	ω
	$f - g$	.075	ω
	$g - h$	.050	ω
	$h - i$	.025	ω
Total drop	$a - i$	.900	ω volts.

The total drop was to be 2 volts, so that

$$2 = .9\,\omega$$

$$\omega = 2.22 \text{ ohms per } 1000 \text{ ft.}$$

The nearest size to this is number 13 wire, B. & S. (See table.)

The Tapered Conductor. In the case just taken, the wire was of the same size throughout the length of the circuit. This necessitated the use of a conductor between *h* and *i* large enough to carry four amperes, although but one-half ampere actually flowed between these two points. Figure 4 shows a similar case in which the first hundred feet of conductor carries sixty amperes; the second, fifty; and so on. The losses in volts and watts are marked on the diagram and their values show that at the right hand side the wire is much larger than is necessary. The ideal arrangement for wiring a system of lamps like figure 1 is shown in figure 2. Having determined the allowable drop from dynamo to lamp, a separate wire is run to each lamp and the same drop

allowed in each. In this way each lamp has the same voltage and one lamp does not interfere with another. This plan would not be wasteful of copper, for exactly the amount of copper would be used as would cause the required drop, and no more. Moreover, each wire would be carrying a current in proportion to its size, which was not the case in figure 1.

WIRE TABLE.

FOR USE IN HOUSE WIRING CALCULATIONS.

B. & S. Gauge Number.	Diameter. Inches	Ohms per 1000 feet.	Current Capacity. Amperes.		Pounds per 1000 feet.
			Concealed.	Open work.	
0000	.460	.0490	218	312	640.5
000	.409	.0618	181	262	507.9
00	.365	.0780	150	220	402.8
0	.325	.0983	125	185	319.4
1	.289	.1240	105	156	253.2
2	.257	.1564	88	171	200.9
3	.229	.1972	75	110	159.3
4	.204	.2487	63	92	126.3
5	.182	.3136	53	77	100.2
6	.162	.3954	45	65	79.4
7	.144	.4987	38	55	63.0
8	.128	.6529	33	46	49.9
9	.114	.7892	29	37	39.6
10	.102	.8441	25	32	31.4
11	.091	1.254	20	27	24.9
12	.081	1.580	17	23	19.7
13	.072	1.995	14	19	15.6
14	.064	2.504	12	16	12.4

NOTE.—Number 14 is the smallest size of wire allowed by the fire insurance underwriters, except in lighting fixtures and flexible cords. The carrying capacities here given are those specified by the underwriters.

The large number of separate wires that would be required for the ideal arrangement makes it necessary to adopt a scheme which will be easier to install, and this is accomplished by combining the

conductors in figure 2 into one conductor, the section of which will diminish as the current to be carried is less. This produces the form shown in figure 4, which is known as the "tapered" conductor. This is not as efficient as the same amount of wire used separately, for, as the calculations show, the drop at the remote end of the line is greater than it would be with separate wires by .26 of a volt. By the use of the tapered conductor, therefore, the drop has been increased a slight amount. Now, if the cross-section of the whole line be increased by an amount equal to twenty-six one-hundredths of its first value, the total drop will amount to the same as in the ideal case. The tapered conductor either causes a slightly greater drop than the ideal case, or a larger wire must be used. In the ideal case all of the lamps have the same pressure, while with the tapered conductor, those nearest the dynamo have a higher pressure than those more remote.

Although the tapered conductor is not equal to the ideal case, it is a great improvement over the single wire of uniform section. This is shown by a comparison of the calculations in figures 3 and 4. These two conductors contain exactly the same weight of copper and both carry the same current, yet the tapered conductor causes ten one-hundredths of a volt less drop and 12.2 watts less loss in power.

Case 2. (See fig. 5). As before, the specifications call for a given drop between the dynamo and the most remote lamp. The figure shows a case in which the lamps are connected to branches which are themselves branches of the main line. It will evidently be impossible to use the same size of wire throughout, and an adaptation of the tapered conductor must be employed. As it would be useless to carry the calculations to the case of each individual lamp, these are considered in groups, and the distance from the dynamo is measured to the center of gravity of each group. The lamps on each of the small branches are considered as making up a group.

The first approximation will be made on the supposition that each group of lamps is connected with the dynamo by a separate pair of wires, and that these are made of such size as to cause the specified drop at each group of lamps. The size of these wires is readily determined on knowing the amount of current to be carried, the length of wire. and the allowable drop. This operation is shown in figure 6, where each pair of wires is represented by a single line. Then all the wires which run parallel are combined

into a single conductor with an area equal to the sum of the s rate areas. As before, this causes a total drop greater than ideal case and the area of the whole tapered conductor must b creased so as to bring the extreme drop to the specified amou

Greater refinement of calculation than is here obtained is necessary because all the lamps are never burning at the s time, and any disarrangement of the number of lamps in ci changes the drop at each. It is then useless to make elab calculations of the drop, the only requirement being that wher lamps are all on, the maximum drop shall not exceed a spec amount.

In practice it is never allowable to connect together directly different sizes of wire. The insurance companies insist that w a branch joins a main the wires shall be connected through " blocks," the fuse being a piece of fusible wire which will mel fore the current has attained a value at which it would unduly the conductor. In figure 6 these fuse-blocks would be insert a', b', c', d', e' f', and g'

PLATE IV

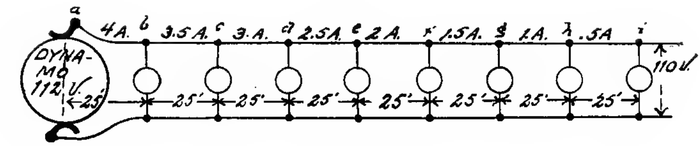


FIG. 1.

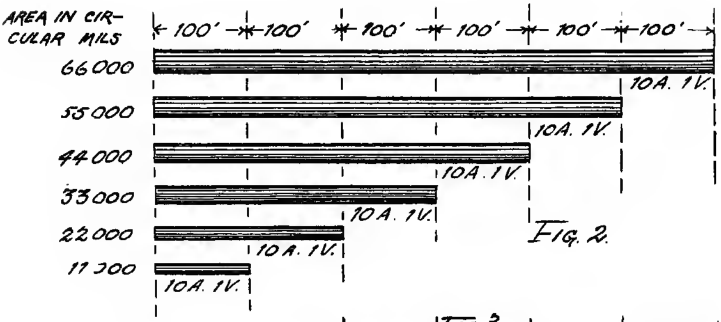


FIG. 2.

FIG. 3.

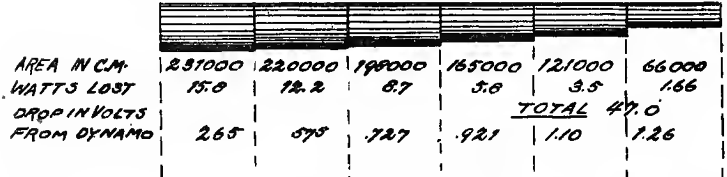
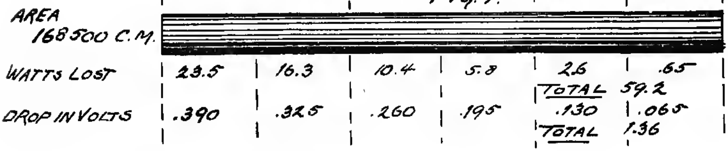


FIG. 4.



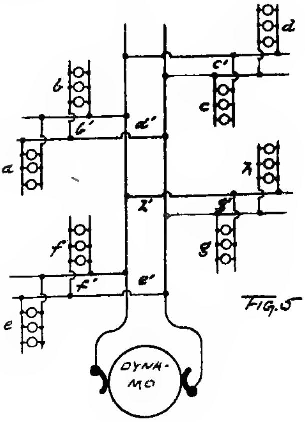


FIG. 5

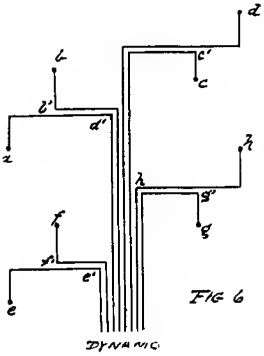


FIG 6

THE STATIC TRANSFORMER AS A COMMERCIAL APPARATUS.

The Alternate Current Transformer is a static device by which the line pressure supplying the alternate current energy is changed as desired, or as the needs of practice demand. In Fig. 1 the appliance at *B* is a transformer for elevating the line pressure developed by the alternator at *A*, at the same time diminishing the current proportionally. At *D* a similar transformer is used for lowering the line pressure, with corresponding increase of current to suit the electrical requirements of the receiving machinery or appliances. This is done to save copper in the transmitting line. This saving, we have seen, increases at a given line efficiency with the square of the line pressure.

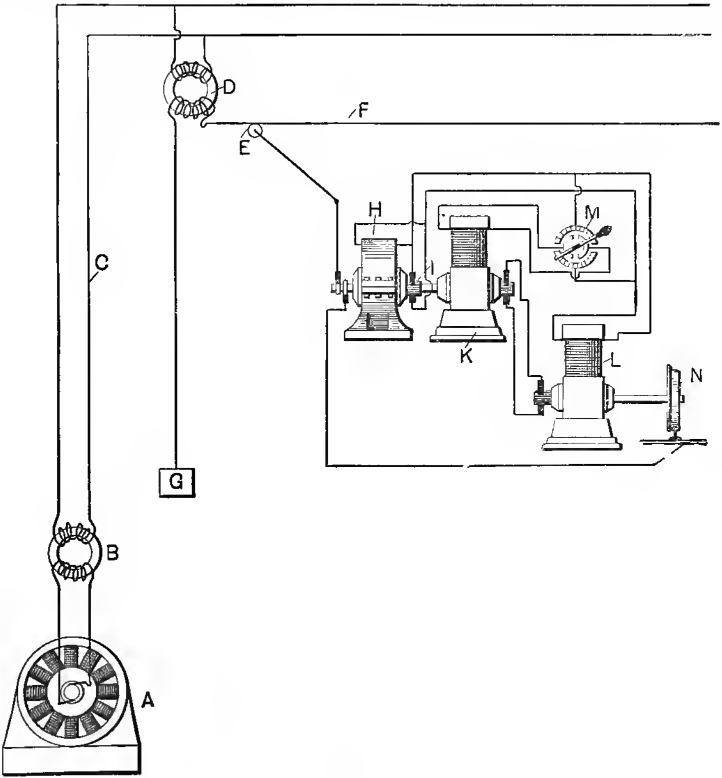


FIG. 1.

Detail of a practical transformer for incandescent lighting circuits. The diagram of a transformer at *B*, in Fig. 1, shows the members of this apparatus, the primary or receiving coil connected to the generator, the secondary discharging coil that delivers the alternate current energy with E.M.F. and current transformed as desired, and the magnetic circuit common to both coils.

Fig. 2 gives a sketch to scale of the cross section and side of a 500 watt, 1000 volt—50 volt transformer that was made in this country about 1888, and operated on the 1000 volt, 133 p. p. s. alternating current lighting circuits of a Buffalo lighting company. The primary coil is the one on the right, and the one on the left is the secondary. A double magnetic link, built up of thin sheet iron, as shown in the figure, forms a magnetic circuit of small reluctance common to both coils. Below are given the data of construction of this transformer :

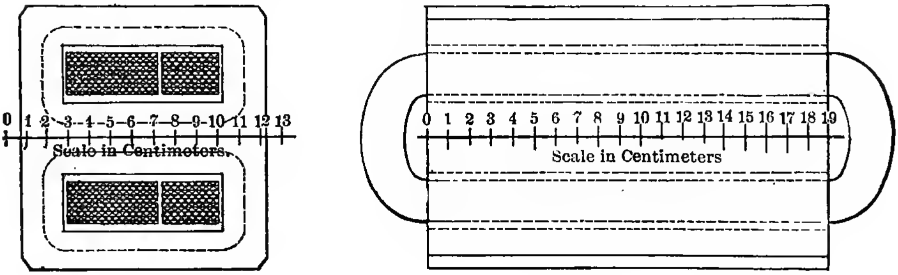


FIG. 2.

Turns in primary coil, 700.
Resistance of primary coil, in ohms, 21.8.
Turns in secondary coil, 35.
Resistance of secondary coil, in ohms, .04.
Average length of magnetic circuit, cms., 30.
Cross section of magnetic circuit, sq. cms., 66.
Volume of magnetic circuit, cu. cms., 2000.

To study this transformer, note first what will occur when the terminals of the primary coil are connected to the service mains that supply an alternating pressure of 1000 volts at 133 p. p. s., while the terminals of the secondary coil are not connected to anything, so that the coil would, therefore, be on open circuit.

What current would be set up through the primary coil? The current will be given by the impedance expression,

$$C = \frac{E}{I_{mp}}.$$

$I_{mp} = \sqrt{R'^2 + L^2\,\omega^2}$, where R' = the resistance of the primary coil, L its coefficient of inductance and $\omega = 2\,\pi \times$ p. p. s. It will be remembered that the inductance of a coil equals the product of the lines of induction set up per unit of current into the number of turns of which the coil is made up. This is the value of inductance in c. g. s. units; for practical units this value must be divided by 10^9 c. g s. $L = M$ per unit current $\times\, t'$, where M is the total induction flux and t' is the number of turns in the primary coil. $M = \frac{\mu\, a\, H}{l}$, where H = the m. m. f., μ = permeability, a = area, and l = length in the c. g. s.

$H = 4\,\pi\, t'\, i$, where i is the current in the c. g. s. Substituting with i at unity and dividing by 10^9 to reduce to practical units

$$L = \frac{4\,\pi\, t^2\, \mu\, a}{10^9\, l}.$$

At the lower values of B, $\mu = 590$ for iron of the quality that was used for making the magnetic circuit of this transformer. Substituting the numerical values,

$$L = \frac{4\,\pi\, 700^2 \times 590 \times 66}{10^9 \times 30} = 8 \text{ henrys.}$$

The impedance,

$$\begin{aligned} I_{mp} &= \sqrt{21.8^2 + 8^2\,(2\,\pi\, 133)^2} \\ &= \sqrt{4750 + 44{,}000{,}000} \\ &= 6685.4. \end{aligned}$$

The current that will be established through the primary coil with the secondary on open circuit will, therefore, be

$$C = E \div I_{mp} = 1000 \div 6685.4 = .14958, \text{ say } .15 \text{ amperes.}$$

The student should note that R'^2 in this instant is very small when compared with $\omega^2 L^2$, and, therefore, that the resistance in this instance has not appreciably increased the induction reactance or the impedance due to inductance. The reactance E. M. F. = $\omega\, L\, C = 2\,\pi\, 133 \times 8 \times .14958 = 999.9$ volts. The small current of .15 amperes through the primary coil in this instance is employed

entirely in establishing an induction in the magnetic circuit sufficient to produce a reactance E.M.F. in the primary coil that is not appreciably less than the impressed pressure of 1000 volts from the line. The reactance E.M.F. is, therefore, practically equal and exactly opposite to the line pressure. As there are 700 turns in the primary coil, each turn develops a reactance E.M.F. of 1000 ÷ 700 = 1.43 volts.

Another, and perhaps a simpler view to be taken of the development of this reactance E.M.F is that it is produced by the alternating induction in the magnetic circuit established by the current just determined.

E.M.F. developed in the secondary coil. Since the secondary coil surrounds the magnetic circuit in common with the primary it follows that each of its turns will have an E.M.F. developed in it equsl to the reactance E.M.F. per turn developed in the primary. The E.M.F. thus developed for the entire coil will be $35 \times 1.43 = 50$ volts. Observe that this E.M.F. is not opposing another E.M.F. as is the case in the primary coil. The E.M.F. thus produced by induction set up through it by the reactance behavior of the primary is, therefore, entirely free to establish current when the circuit of the secondary is closed. Assume that the secondary circuit is closed through a non-inductive resistance r, as for example 10, 50 volt 16 c.p. lamps taking one ampere each. On closing the secondary circuit some current will be established. This current through the secondary coil will set up a m. m. f. that will oppose the m. m. f. of the primary coil. To see this the student should review the above statements, noting that the secondary E.M.F. is relatively diametrically opposed to the line pressure which sets up the magnetizing current through the primary coil against the developed reactance E.M.F. Cutting down the m. m. f. in the magnetic circuit will lessen the induction and, therefore, the reactance E.M.F. This will increase the amount by which the line pressure exceeds the reactance E.M.F. so that more current will be set up through the primary coil. It is seen then that the moment the secondary circuit is closed the impedance of the primary coil has been greatly changed since its capacity to admit current has been enlarged.

Impedance of the transformer with the secondary on closed circuit. Let r be the resistance in circuit external to the secondary coil, and R' and R'' the resistances of the primary and secondary coils. Bearing in mind that the m. m. f. of the primary and

secondary coils, as applied in the common magnetic circuit, are directly opposed to one another, the impedance of the transformer which governs the current which will be admitted to the primary coil will be,

$$I_{\mathrm{mp}} = \sqrt{\left[R' + \left(\frac{t'}{t''}\right)^2 (R'' + r)\right]^2 + \omega^2 \left[L' + \left(\frac{t'}{t''}\right)^2 L''\right]^2}$$

where t' and t'' are the primary and secondary turns respectively, and L' and L'' are the inductance coefficients for the primary and secondary coils for their own local magnetic circuits.

The primary current that is being transformed will be,

$$C' = \frac{E'}{\sqrt{\left[R' + \left(\frac{t'}{t''}\right)^2 (R'' + r)\right]^2 + \omega^2 \left[L' + \left(\frac{t'}{t''}\right)^2 L''\right]^2}}.$$

It is customary for the beginner to look at the behavior of the transformer, by assuming that L' and L'' are so small that they may be neglected, when the above expression becomes,

$$C' = \frac{E'}{R' + \left(\frac{t'}{t''}\right)^2 (R'' + r)}.$$

From this it is seen that the transformer, when the secondary circuit is closed, admits current to the primary coil as though it were a simple resistance having a value

$$R = R' + \left(\frac{t'}{t''}\right)^2 (R'' + r).$$

The secondary current will be

$$C'' = \frac{C'\,t'}{t''}$$

and the pressure at the secondary terminals will be $E'' = C''\,r$. The total primary current, neglecting a small current that supplies a hysteresis loss in the magnetic circuit will be

$$C = \sqrt{C'^2 + C'^2_{\mathrm{L}}}$$

Effect of primary and secondary independent inductance, L' and L'' It is not practicable to build transformer coils so that L' and L'' will be entirely zero. The diagram of Fig. 3 gives the input—output efficiency, regulation and C^2R loss curves for the above 500 watt transformer. The regulation curve gives the secondary delivered pressures at various secondary outputs. At the full load secondary output of 500 watts it is seen that the secondary delivered pressure has dropped from 54 to 49 volts, or 5 volts, the primary pressure being 1080 volts throughout. This is a serious variation for incandescent lighting. Had L' and L'' in this transformer been practically zero this drop would have been,

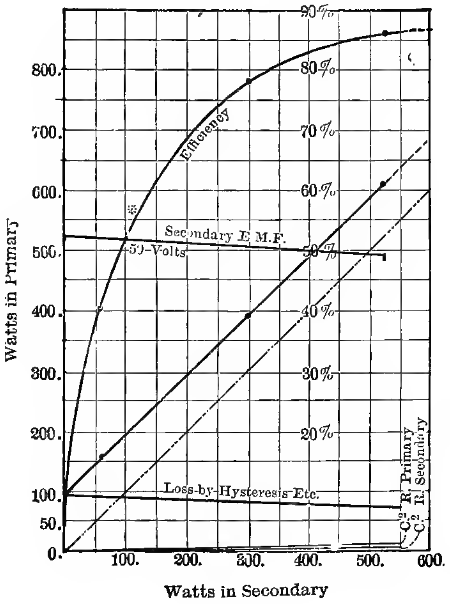


FIG. 3.

$$\frac{E'\,t''}{t'} - \frac{E'\,r\,t'}{\left[R' + \left(\frac{t'}{t''}\right)^2 (R'' + r)\right] t''}$$

$R' = 21.8$ ohms; $R'' = .04$ ohms; and $r = 5$ ohms.

Substituting,

$$54 - \frac{1080 \times 5 \times 700}{\left[21.8 + \left(\frac{700}{35}\right)^2 (.04 + 5)\right] \times 35} = .94 \text{ volts.}$$

It appears, therefore, that of the 5 volts observed drop in secondary pressure practically but 1 volt is due to ohmic resistance and the remainder to L' and L'' The existence of L' and L'' in annoying quantities is due to the fact that these primary and secondary coils of this transformer establish magnetic induction about themselves within the space they individually occupy and independently of one another. In all modern transformers the coils are so formed as to make the length of the path of the local inductance as great as possible. This is accomplished by making the coils thin, as shown in Fig. 4. By this means the values of L' and L'' are diminished to such an extent that the total secondary drop in pressure at full incandescent lamp load is not more than double the drop due only to the ohmic resistance of the coils.

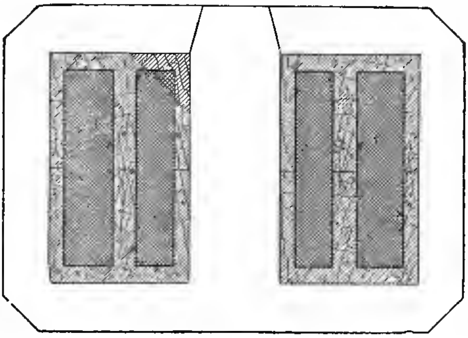


FIG. 4.

The function of the primary exciting current which was found when the secondary circuit was open, is to establish the induction in the magnetic circuit, which in turn forms the resistance E.M.F. As this resistance E.M.F. plus the fall of potential through the primary coil, which is always small, must at all times equal the line pressure, it follows that the induction and the current which establishes it diminish with the load but slightly. In the above ten light transformer at full load the resistance E.M.F. equals $1000 - \left(10 \times \frac{35}{700} \times 21.8\right) = 989$. This is a diminution of about one per cent., a proportion in which the induction and the reactance current are also diminished. Since this variation is small, these quantities are generally thought of and spoken of as remaining practically constant at all loads. This reactance current must be superimposed or added to the primary transformed current, as no

part of the transformed current can set up induction through the magnetic circuit that is common to both coils. Since the purpose of this current is to form reactance E.M.F. and, therefore, to establish induction, it is sometimes spoken of as the transformer magnetizing current, though more frequently than by any other expression it is called the transformer exciting current. This exciting current has a rather complex duty to perform owing to the fact that it must in addition to providing the alternating ampere turns of m. m. f. that are necessary to alternate the induction in the iron by the necessary amount, it must convey the electrical energy that is taken up in the iron through the phenomenon of hysteresis and given out as heat. The maximum value to which the induction in either direction must be conveyed so as to produce a reactance E.M.F. of 1000 volts is,

$$M_{\text{max}} = \frac{1000 \times 10^8}{\sqrt{2}\,\pi\,700 \times 133} = 257{,}000 \text{ lines.}$$

Figure 5 gives two curves showing the relation between the

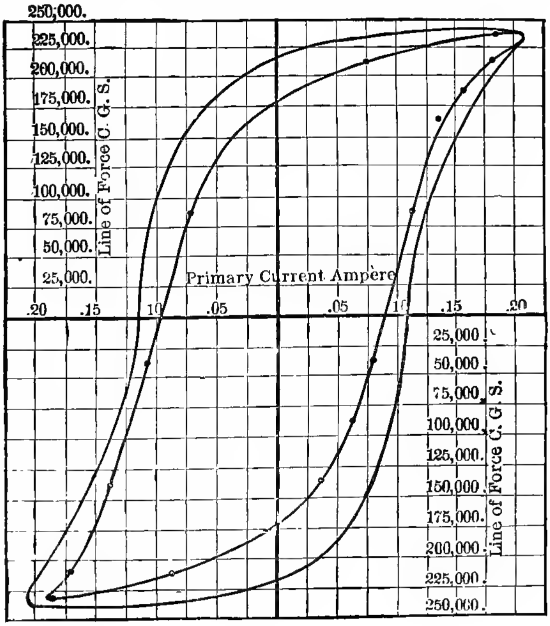


FIG. 5.

current through the primary coil, with the secondary on open cir-

cuit, and the corresponding induction established through a complete cycle. The inner curve or card was obtained by taking a a long time in which to carry the induction through a complete cycle of variation ; the outer card gives this relation by taking the induction through the complete cycle in $\frac{1}{133}$ second. The difference is due to the eddy currents in the iron that set up m. m. f.'s in the iron circuit opposite to those formed by the primary coil, thus requiring more current for the quick than the slow cycle. In this process of cyclic variation of induction the iron absorbs electrical energy from the electric circuit that sets up the induction, by requiring more current to establish a given induction when the induction is increasing than when it is diminishing. On this account the transformer exciting current, when producing smooth curves of induction and reactance E.M.F., is irregular in form, (see Fig. 6) and occupies a time position with respect to the line E.M.F. so as to extract line energy that must be supplied to the iron to be transformed into heat through the hysteresis of alternating induction. Since 1887, when this transformer was manufactured, great improvements have been made in the manufacture of sheet iron or steel for these purposes. A brand of soft sheet steel is now marketed by the Apollo Iron and

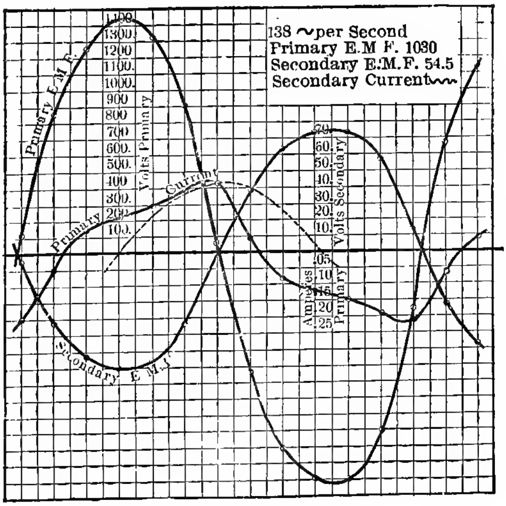


FIG. 6.

Steel Co., of Pittsburg, Pa., which if used to make the core of this ten light transformer, would have caused the transformer exciting current energy to be 25 instead of 96 watts.

THE INDUCTION MOTOR

The Induction Motor is a special type of transformer in which the secondary coil moves with respect to the primary. Mechanical power is given out by the secondary, the measure of which is the product of the secondary current into the E.M.F. mechanically formed by the motion of the secondary conductors through the alternating induction established by the exciting current of the primary and into the cos θ if there is secondary local induction. When the induction motor is to be self starting, it is necessary that there be more than one set of primary and secondary coils. Each primary is supplied independently with a line pressure that is equal to the line pressure on the other primary coils, but differing in phase from each of them. It is through these phase differences that the proper relation of magnetic induction and secondary currents to maintain continual mechanical motion is obtained. There are two types of self starting induction motors, distinguished by the number of differing phases supplied to corresponding primary and secondary circuits. The two phase motor is marketed chiefly by the Westinghouse and Stanley electric companies. This motor uses two sets of primary and secondary coils. The primaries are supplied with equal and separate line pressures differing in phase by one-quarter period. The three-phase induction motor is principally marketed by the General Electric, and the Siemens and Halske companies. In this type three sets of primary and secondary coils are used. The primaries are supplied with independent line pressures equal in amount and each differing in phase from the remaining two by 120°. The principles of behavior of the two types of motor are identical. The two-phase motor appears the simpler to the beginner. For this reason it is selected for the following demonstration of the characteristic behavior of the induction motor.

Induction motor behavior. In Fig. 1 is given a diagram showing the arrangement of a single portion of the two sets of primary

and secondary coils with respect to themselves and their magnetic circuit for a two-phase induction motor. This diagram is drawn

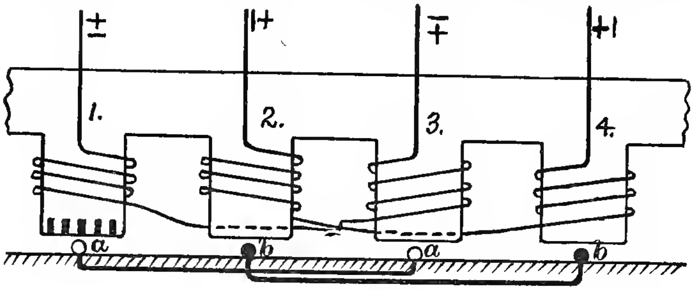


FIG. 1.

so as to be characteristic of the particular form of induction motor marketed by the Stanley Electric Co., of Pittsfield, Mass. Though the action in this type is identical with that of all others, it is so modeled as to make this action more readily apparent to the student who is new to this subject. The coils 1 and 3 form one primary, and 2 and 4 the other; 1 and 3 have a common magnetic circuit independent of 1 and 3. The magnetic circuits are closed across an air gap through the laminated iron that supports the secondary coils, *a a*, and *b b*. The air gap is necessary for mechanical clearance, permitting the secondary coils, together with that portion of the magnetic circuit upon which they are mounted, to move relatively to the primary coils and their magnetic circuits. Assume now that the two-phase line pressures are applied at the terminals 1 and 3, and 2 and 4. Assume also that the 1 and 3 pressure is one-quarter period or 90° in advance of the 2 and 4 pressure. Consider the secondary circuits, *a a* and *b b*, on open circuit for the time being. An exciting current will now be established through each set of primary coils equal to

$$E' \div \sqrt{R'^2 + \omega^2 L^2}.$$

R'^2 is very small when compared with $\omega^2 L^2$ and may be neglected, when the expression for the exciting current becomes $C_{ex} = E' \div \omega L$. The reactance E.M.F under these circumstances is practically equal and opposite to, or 180° back of, the impressed E.M.F., E' The phase position of the magnetic induction is always 90° in advance of the reactance E.M.F. that it produces and, therefore, 90° back of the impressed E.M.F. When an air gap exists in a mag-

netic circuit, as is the case here, the position of the total exciting current, including hysteresis and Foucault current effects is almost identical with the phase position of the magnetic induction, being slightly in advance of it and, therefore, not quite 90° behind the impressed E.M.F. Consider now that the secondary *a a* is closed through a non-inductive resistance sufficient to limit properly the current induced in it by the magnetic induction from 2 and 4. The current thus established through the secondary conductors *aa* is due to and in unison with the reactance E.M.F. that is 180° the pressure on 2 and 4. These conductors are located in a field of induction that has exactly the same time position with reversed sign. This is easily seen from the fact that the pressure on 1 and 3 is 90° in advance of 2 and 4; that the 1 and 3 induction is 90° behind the 1 and 3 pressure and, therefore, in the same phase position as the 2 and 4 pressures; hence the current in *a a* is 180° behind both the line pressure 2 and 4 and the induction 1 and 3 in which *a* and *a* are located. As a change of phase of an alternating quantity of 180° is equivalent exactly of a change of sign of that quantity, the fields at *a a* will act on those currents just the same as though they were in unison, with the exception that the effort to mechanical motion will be opposite in direction. The student should remember that a change in the sign of both field and current at the same instant will not change the direction in which the current will move through the field. Similarly *b* and *b* will have a current induced in them that will be acted on mechanically by the induction through the circuit 2 and 4. A study of the signs, directions of currents, inductions and mechanical motions in each of these secondary coils, will reveal the fact that the coils *a a* and *b b* will be moved in the same direction, in this instance toward the left. Permit these conductors to move. In an instant the coil *b b* has moved into the position just occupied by *a a* and is acting, therefore, exactly as *a a* acted, while *a a* has moved forward to a position corresponding to *b b*, behaving as *b b* did, and both tending at all times to move to the left. Reversing one of the primary pressures would make this motion take place from left to right. The conductors, by continuing their motion, soon attain a velocity such that the E.M.F.s produced by the mechanical motion across the magnetic induction through which they are passing, become appreciable. As the E.M.F.s are opposite the secondary induced E.M.F., the currents in *a a* and *b b* are cut down and there is no tendency for the speed to increase. The

resistance in circuit with *a a* and *b b* may now be cut out gradually, the secondary velocity will again increase, thus developing more mechanical E.M.F. until finally a point is attained where all of the secondary resistance has been cut out and the secondary is driving at full speed. At this point the counter E.M.F. mechanically formed, is practically equal to the the secondary induced E.M.F. Should the secondary structure now be called on to do mechanical work, it will lessen its speed a trifle, thus lessening the counter E.M.F. and permitting the induced E.M.F. to set up more current, producing more torque and maintaining the load without further lowering the speed. What drop in the speed does occur is small, because the resistance in the secondary conductors is low and the currents producing the load torque effect but small falls of potential when compared with the impressed and counter E.M.F.s. As the difference between the secondary induced and counter E.M.F.s will be proportional to those falls of potential, it follows that such differences will be small, the variation of counter E.M.F. be small, as will be the corresponding variation of speed.

Fig. 2 gives a side and vertical cross-section of a Bradley two-phase induction motor. There are two independent motor secondary structures mounted on the same shaft. In the right structure, which is enclosed by the primary or outer structure, a starting resistance is permanently inserted in the secondary circuits. In the left structure not enclosed by the primary, the secondary circuits contain no additional resistance and are to be used when the secondary structures are brought to full speed. When this motor is started the primary is in the position shown in the figure. As the secondary comes to speed by means of the hand lever, *4a*, the primary is moved to the left so as to use the secondary that contains no starting resistance. Many other forms

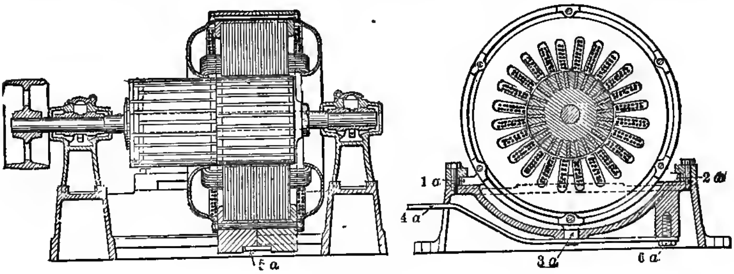


FIG. 2.

are adopted in practice to control properly the starting currents.

Induction motor characteristics. The torque speed characteristic curves of an induction motor operating from a multiphase con-

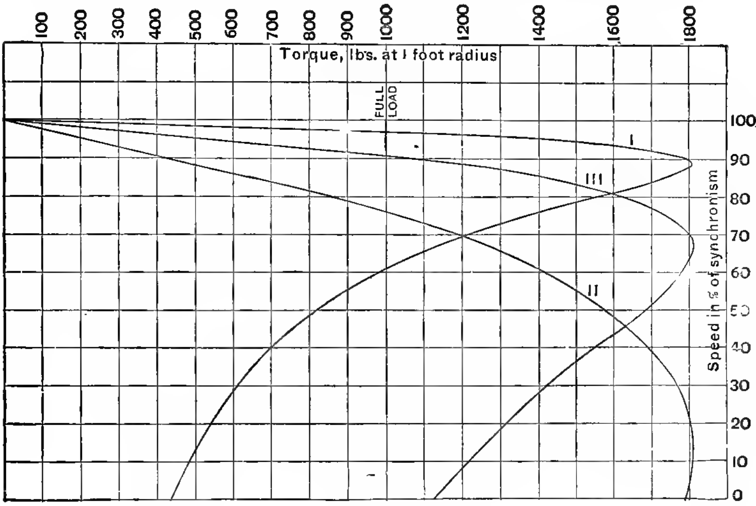


FIG 3

stant potential circuit are given in Fig. 3. Curve *I* shows the relation of torque and speed when all of the secondary starting resistances are cut out. Note that the starting torque is small, while at full speed and load the motor drops but little below the no load speed. The excessive dropping off of the torque at the low speeds is due to secondary inductance, which shifts the phase position of the established currents so that they produce but little torque. The insertion in the secondary circuit of fall of potential due to non-inductive resistance or of mechanically formed counter E.M.F., limits the secondary currents and maintains them more nearly in unison with the secondary induced E.M.F., the position they must occupy in order to produce torque. Curve *III* is like curve *I*, except some secondary starting resistance has been used. Curve *II* was obtained when the secondary starting resistance was so adjusted that the starting torque should be a maximum. In practice some starting resistance is used that will give a sufficient starting torque. The motor will start and come to speed along a characteristic curve like *II* or *III*. As this is done the resistance is gradually cut out, being all out when the motor is running at full speed and when it will give a performance like that of curve *I*.

The Synchronous Motor. The first alternators that were used in our country about ten years ago had smooth bodied armature cores, upon which was operated a minimum amount of copper. The armature self-induction and reactive effects amounted to so little that we may neglect them, when making an examination of that which should be their behavior when operated as synchronous motors. In Fig. 1, E, E' and E'' are the generator, motor, and resultant pressures,—E'' is the difference between E and E'. When E and E' are equal, as in this figure, at the moment of synchronized connection of the motor with the generator, E'' will have no value. E'' is the E.M.F. upon which depends the establishment of current through the motor. With E'' at zero the motor current will be zero, no power will be developed, and the motor will immediately fall behind the generator to some point like *d*. Here E'' has a large value. The circuit of the two armatures and line possesses some resistance and a negligible amount of self-induction. Current will be established in unison with E''. We see, however, that no current which occupies the time position of E'' can produce power in the motor, for all such current is as much in unison with the motor as it is with the generator E.M.F's. Under such circumstances the motor will quickly come to rest. We now diminish the field of the motor and thus lower its E.M.F., E', as in Fig. 2. At the moment of synchronized connection $E \dot{-} E' = E''$ will be in unison with E and opposite to E' The current that E'' establishes occupies the same time relation, and mechanical power equal to CE' is produced at a power fraction of unity. In general this will be more

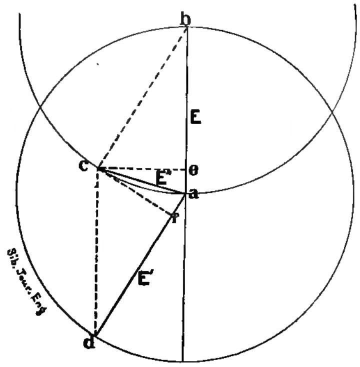


FIG. 1.

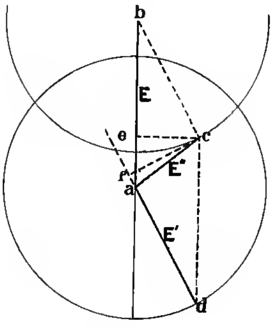


FIG. 2.

than sufficient to keep the motor at this speed position, and it will be accelerated to some position like *d*. At *d* we find E'' and, therefore, C is greatly increased while the developed power which is proportional to af is much diminished. Thus the motor takes up some position where the developed power is equal to the demand made upon it.

Increase in the demands on the motor for power will cause it to fall back in speed position until the point of exact synchronism is again attained, after which it will come to rest, for it is evident from the diagram that at this point af attains a maximum value. Note that the power factor is high only at the point where the motor is about to stop on an attempt being made to further increase the load. It is evident that such a motor would be very unsatisfactory in practice. On adjusting E' so that the motor will be reasonably free from the danger of losing synchronism, the power factor is much diminished. Under the most favorable circumstances a motor of this class should stand a half over-load suddenly applied without going out of step. Then frequently in practice a motor is loaded on the average to no more than 50 per cent. of its rated output. All this points to an average working power factor that is less than 50 per cent. to be realized by this class of synchronous motor.

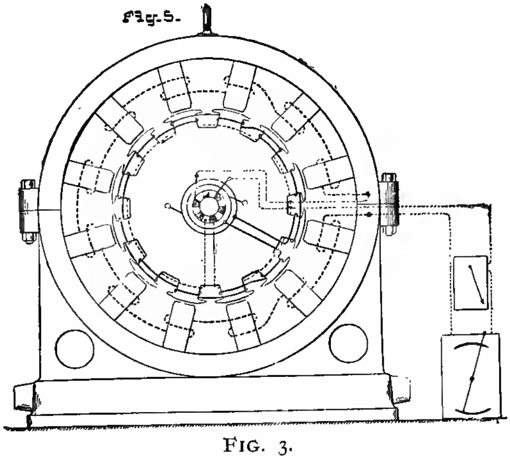


FIG. 3.

Five years ago the T-toothed alternator armature was introduced for electric lighting. (See Fig. 3.) This design is now largely superseding the smooth-bodied type because of its structural superiority. Makers had not gone far in their experience

with machines of this type before they realized that they possessed some features of special excellence for operation as synchronous motors. They differ electro-magnetically from the smooth core armatures through their large self-induction and armature reactive properties. The former property changes the time position of the current with respect to E'', while the latter acts to equalize E and E', however these may differ, though such action amounts to very little when the power factor is high, as it must be in most cases.

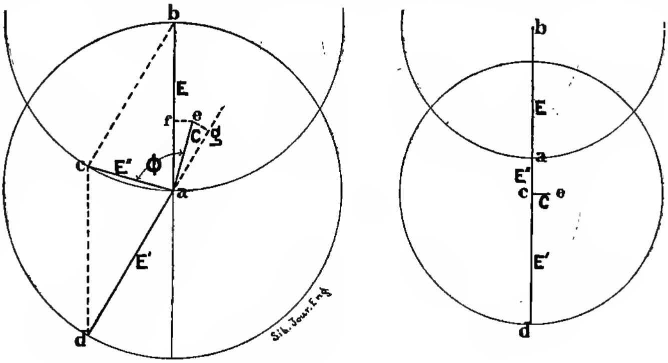
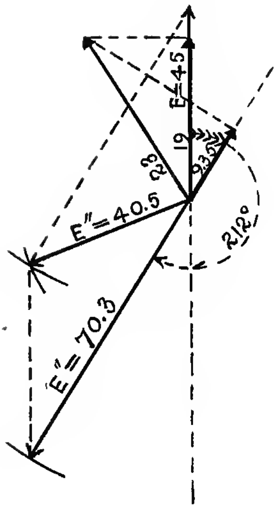


FIG. 4

Consider then that in Fig. 4 we have represented the conditions for a synchronous motor with a T-toothed, or iron clad armature. The fall of potential will be small as compared to the reactance due to inductance, and E'' will establish current at a time position that is practically 90° behind itself. By starting with E and E' equal, the motor will promptly take up such a lagging position as *d*. Now note that *C*, as established by E'', is right in the position required for the maximum obtainable power factor. See that this current has come up in proportion to the power demanded, and that it will continue practically to do so, even to the point where E'' is 50% of the value of E. Ultimately, as in all other cases, a point is found where the power factor diminishes so rapidly that *ag*, proportional to the developed power, no longer increases, and beyond that the motor quickly comes to rest. The design is easily arranged so that this point will be at almost any desired over-load. On coming to rest, too, this motor will suffer nothing from the sudden rush of current that takes place, because the inductance of the armature places a convenient limit upon the



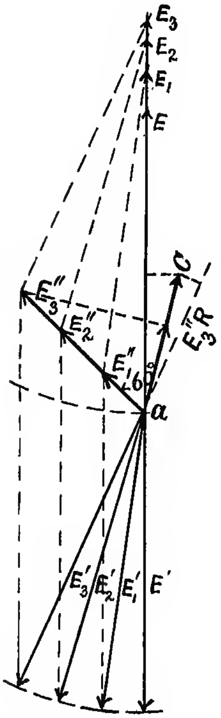
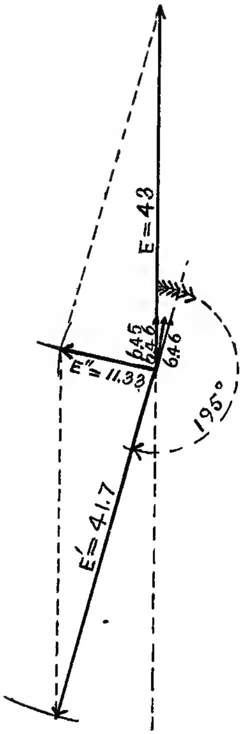


Fig. 5.
Fig. 7.



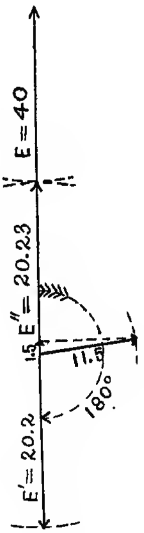


Fig. 6.
Fig. 8.

greatest possible current that can be established. The circuit breaker will cut off such a current before damage can be done.

Fig. 6 illustrates the actual behavior of a motor in which the field was adjusted so as to bring the current, 6.46 into the position, where the greatest power factor is obtained. The relation of the inductance and resistance of the motor circuit was such as to make C 82.5° behind E''. E and E' are nearly alike,—they differ 1.3 volts, the drop in the line.

Fig. 8 shows the behavior of this same motor when its field excitation is greatly reduced, and Fig. 4 is the corresponding behavior with field excitation greatly increased. You see that with the weak field the motor currents take up a position behind E and with a strong field a corresponding position in advance of E, the general pressure. The power factor is greatly reduced, and the conditions, therefore, are undesirable for practice. Note that the reactive effects of these currents on the motor field in all cases are to make the motor E.M.F. more nearly like that impressed by the generator. In this connection it is necessary to remember that a lagging current lowers the field of the generator, and an advance current raises it; the opposite occurs in the motor.

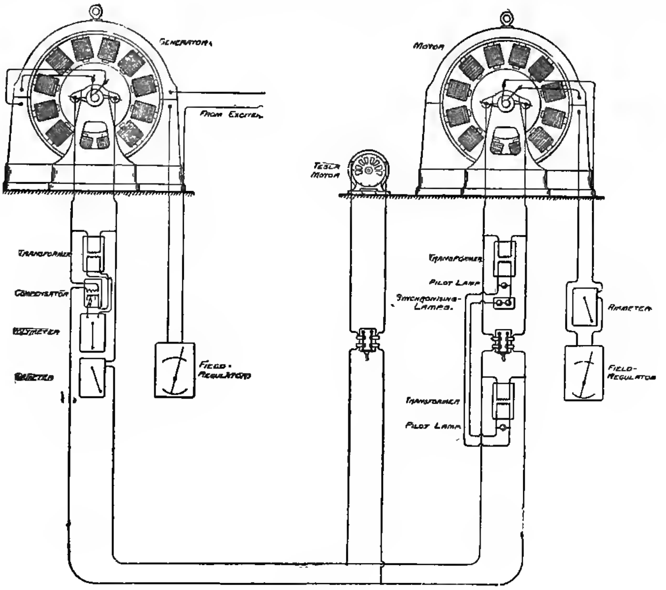


FIG. 8.

In order that the output of a motor be as high as practicable

for a given size of machine at a given first cost, it is necessary to operate at the highest practicable power factor. This is easily accomplished when we do not have to deal with a line on which there is considerable drop, say from 10% to 30 or 50%. The effect of the resistance of the line is to lessen the angle that the current occupies behind E″. In Fig. 7 we have illustrated a case where the inductance and resistance of the lines and motor circuit are such that the current will be 60% behind *E″* Here, for the highest power factor at average loads, we must have the current remain slightly at the rear of *E*. To do this it is necessary to compound the generator producing *E*, as indicated in the diagram, so that *E″* will remain approximately in the same position, as Fig. 6 shows at all loads.

Single phase synchronous motors are generally started by means of a special, single phase auxiliary induction motor, that is self-starting under load, though inefficient, and is used for starting purposes only. (See Fig. 8.) A small generator answers very well as an exciter,—though frequently alternating current from an auxiliary winding on the synchronous motor armature is used for excitation when rectified by a two part commutator.

The Rotary Transformer. Any ordinary direct current bipolar generator that employs a closed coil armature may readily be converted into an alternator by mounting over the commutator two collector rings, connected to diametrically opposite commutator bars. An alternating pressure will be developed between brushes placed on these rings, the maximum value of which will be equal to the direct current pressure that the armature will develop between the normal points of commutation on the commutator. The working value of an alternating E.M.F. obtained in this way would therefore be $E_{dc} \div \sqrt{2}$ where E_{dc} is the direct current pressure. The periodicity of a two pole machine would, in general, be too low for most practical purposes. When, therefore, a direct current armature type of alternator is to be designed the multipolar two path armature and field are selected. The collector rings would be mounted on that end of the armature shaft which is remote from the commutator, and connected to conductors that pass directly to commutator bars that are separated by an interval of bars that correspond to the pole interval, or the distance on the commutator between neutral points. Two additional rings may be used with commutator connections, midway between those for the first set of rings. The result is that between

the second set of rings an alternating pressure is produced that is maximum when the pressure between the first set is zero, and zero when the first pressure is a maximum. Thus a two phase source of alternating pressure is produced. Similarly a three phase pressure may be obtained by connecting three sets of rings at intervals on the commutator of two-thirds of the direct current commutation interval or the interval assigned to one pole. Views of various types and forms of machines of this class will be exhibited to the class with the aid of the lantern. Such machines may be used to furnish either multiphase alternating or direct currents or both. Being alternators they will work as synchronous motors. When working as synchronous motors they form alternating counter E.M.F.s, due to the rotation of their armatures in the magnetic fields. The same conductor E.M.F. that produce alternating E.M.F.s from collector ring to ring will also form a direct current E.M.F. at the neutral points on the commutator, from which direct current energy may be drawn, just as alternate current energy is drawn from the secondary of a static transformer. Thus this class of electrical machinery has come to be called a rotary transformer. Note then that by supplying one of these rotary transformers with a two phase current at 350. volts, that the direct current energy would be discharged from the commutator at $350 \times \sqrt{2} = 500.$ volts.

The practical utility of the rotary transformer will be discussed in the next lesson.

Phase Transformation in Polyphase Practice. In Fig. 1 two sources of alternating pressure are available as $o' y'$ and $o' x'$. $o' y'$ is one-quarter period ahead of $o' x'$ Transformers with numerous secondary taps, as shown in the figure, enable one to lessen these pressures through efficient transformation by any desired amount, or from the maximum effective secondary pressure to zero pressure. $o x$ and $o y$ are the maximum effective secondary pressures, and $o c$ and $o b$ are corresponding smaller values obtained by adjustment as indicated.

In Fig. 2, $o a$ is an E.M.F. that is obtained by combining in the proper proportions E.M.F.s from $o y$ and $o x$, having the values $o b$ and $o c$. Taken with respect to phase or time position, a new E.M.F. is thus obtained that is $\theta°$ ahead of $o x$ and $90° - \theta$ behind $o y$. Taking the phase position of the new E.M.F. with respect to $o x$, and remembering that angles taken anti-clock wise are positive and those taken clockwise are negative, the relations between θ, $o a$, $o b$ and $o c$, are

$$\cos \theta = \frac{o a}{o c}$$

$$\sin \theta = \frac{o a}{o b}.$$

As it is entirely practicable to vary $o b$ and $o c$ independently from zero to $o y$ and $o x$ respectively, by the device of tapping the secondary coils of the transformers at points corresponding to the desired E.M.F., so θ may be varied without changing the value of the pressure $o a$, from zero to 90°. We are not limited to this amount of variation of θ. In Fig. 1 it is seen that in joining the secondaries in series, the circuit might have been arranged so as to go from o through $o b$ to o instead of to c, of $o x$ and from o through $o c$ to a, then through the working circuit back to o of $o y$. The effect in the circuit of this reversal of one of the E.M.F.s is better seen in connection with Fig. 3. There it is seen that by reversing the sign of $o x$ the new time position that it will occupy is the broken curve $o x$. The phase position of this broken curve is 90° ahead of $o x$ or a total forward change of $o x$ of 180°.

The result in the diagram of Fig. 2 of this reversal in the circuit of the secondary $o x$ is that $o c$ is changed to $-o c$.

The result is that

$$\cos \theta = \frac{a b}{-o c} \text{ and}$$

$$\sin \theta = \frac{a b}{o b}.$$

It is evident now that θ may be made to vary from 90° to 180° by selecting values of *o b* and *o c* as indicated. By reversing *o b* and *o c*, both sin θ and cos θ each change sign and values of θ or the positions of the new E.M.F. ahead of *o x* may be obtained from 180° to 270° Then by rectifying the direction of *o c* so as to make cos θ again positive, and by permitting *o b* to remain reversed, causing sin θ to remain negative, θ of the new E.M.F. may be made to vary from 270° to 360°. Thus by combining sin θ, cos θ portions of two sources of alternating pressure in quadrature, E.M.F.s may be obtained in any desired new phase position.

We will now turn our attention to the system of vector diagrams that is used for determining the new E. M. F.s that result from combinations of polyphase sources of E. M. F. The diagram of fig. 4 is used in lieu of the one in fig. 2. When the vectors are drawn as in fig. 4 the broken line *o b* which completes the triangle corresponds to the diagonal of the parallelogram *o b* (*broken line*) and is, therefore, the pressure put upon the line by the combined E.M.F.s *o b* and *o c*. But the interpretation to be put upon *o b* is that it is the external or working circuit through which the new E. M. F. establishes current. That, however, makes a diagram of mixed E. M. F.s. It is always desired to know the value and phase position that the new pressure will have, not in the direction that it is exerted through the line circuit but in the direction that it is exerted through the circuit of the equivalent source. The equivalent source in this instance would be an alternator coil or another secondary coil whose terminals are connected from *o*, *o b*, *o c* to *b* of *o b* and in which the E. M. F. *o a* would be generated. Such an E.M.F. would impress through the line the pressure *o b* (*broken line*) just as is accomplished by the combined E. M. F.s *o b* and *o c*. The equivalent source E. M. F. is more conveniently found by a continuation of the process by which *o b* (*broken line*) was found. The positive direction of the circuits in which the source E. M. F.s *o c* and *o b* are produced is taken from *b* to *o b* by way of the route *o c*, *o b*. Now to pass from *b* to *o* in the same conductor direction it is necessary to go back through *o b* and *o c* by the route *b o*, *c o* as there is no actual circuit from *b* to *o* direct. In continuing the circuit from *b* to *o* it is seen that the direction of the electric circuit is opposite to the E. M. F.s *o c* and *o b* and that these E. M. F.s are, therefore, reversed with regard to the direct circuit *b o* and the directions of the vectors that represent them should be reversed for determining the equivalent source E. M. F. On reversing the

arrow heads of *o b* and *o c* so as to make these E. M. F.s read *c o* and *b o* it is found that their resultant equals *o a*. Thus by completing the cycle of circuit direction taken throughout with the same sign where two or more sources of E. M. F. are joined in series, that is, by starting through the circuit in a positive direction and continuing through all of the connected sources of E. M. F. their equivalent sources of E. M. F may be determined. It is necessary that the sum of the actual and equivalent E. M. F.s shall be zero at all instants of time. In fig. 4, omitting the broken vector we may designate any instant of time in an alternating cycle by drawing any line of reference through the center of the triangle. The projections of the E. M. F. vectors forming the sides of this triangle will be the instantaneous values of the E. M. F.s. It is seen that the algebraic sum of such projections taken with their proper signs must always be zero.

Fig. 5 gives a vector triangle which determines the equivalent source of E.M.F. when the circuit through the *o x* secondary of fig. 1 is reversed. In fig. 1 *o* of *o c* is now joined to *o* of *o b*, *b* and *c* are now connected to the line to deliver the new E.M.F. instead of *b* and *o* as before. Note in fig. 5 that the positive or anti-clockwise direction of the circuit now begins with *b* and passes through *b o* and *a c*. The actual E.M.F.s that occur in the circuit are taken from *b* to *c* through *o o* and are *o b* and *o c*, while the reverse of this is the positive direction for the circuit of the equivalent E.M.F., *o a*. In passing back through *o c* and *o b*, *o c* is reversed with respect to the direction of the circuit, thus producing the *o a* amount and direction of the equivalent E.M.F. Fig. 6 gives a very common method in practice for connecting three E.M.F. developed by a three phase alternator 120° apart. Note that any one of these E.M.F.s might be omitted and its exact equivalent would be supplied by the two remaining E. M.F.s. Frequently in practice by taking advantage of this fact where a three phase E.M.F. is to be transformed, two transformers are used for transforming but two of the three E.M.F.s, the third being supplied by the combination of the other two. Where this is done the current capacity of two transformers must be about fifteen per cent. in excess of the combined transformer capacity when three transformers are used. In all cases where the transformers are comparatively small or under 10 K.W., three transformers aggregating a capacity of one *1a* will cost more than two transformers whose capacities aggregate *1.15a*. The cost of the two transformers in general being no more than for three and oftimes

less. The greater simplicity which attends the use of two transformers is so desirable that the two transformer plan of three phase transformation is generally adopted.

Frequently the shafts of two similar single phase alternators are coupled together so as to make the development of their E.M.F.s occur at a phase difference of 120°. For example in fig. 6 these two alternators when connected in series would furnish the E.M.F.s *a b* and *b c* and between *c* and *a*, these two E.M.F.s would deliver the exact equivalent of the third of the three phase pressures. Just as in the use of two transformers on a three phase circuit these machines would have to aggregate a slightly greater current capacity for a given K.W. output than a single three phase three coil alternator. The two alternator method of three phase generation is often highly desirable under circumstances where some three phase current is desired for driving alternate current motors while the greater portion of the electrical energy is to be applied for lighting. It is more convenient in practice to do lighting from single phase circuits which would for such purposes be run independently from each machine. For the delivery of power current three wires from the *a b c* terminals of the two machines, *b* being common to both, would be run to the motor. The method of connecting either three or two E.M.F.s 120° apart that is given in fig. 6 is known as the Δ connection from the resemblance of the form of this vector diagram to the Greek letter delta.

The diagram of Fig. 7 is drawn for the study of a method of phase transformation that is now much applied in practice. This method is for the transformation of a two phase E.M.F. source into an equivalent three phase source, or vice versa. The two phase source is *b c* and *d a*. The *d a* pressure circuit at the terminal *d* is connected to the middle of the pressure circuit *b c*. We will first examine this diagram qualitatively. Beginning at *b* and proceeding in a positive direction, we find first the actual pressure *b c* from *c* to *a*, then there is the equivalent pressure *c a* found by continuing in a positive direction through *d c* and *d a*. It is found that also *a* and *b*, *d c* is reversed with respect to the direction of the circuit giving the value *c a*, with arrow head at *a*, as the equivalent source of E.M.F. produced by the combination of *d c* and *d a*. Continuing with the circuit in a positive direction in a similar manner, we find the remaining equivalent E.M.F. *a b* as given by the diagram. Precisely the same values and directions of equivalent E.M.F.s would be obtained if each triangle in Fig. 7 were treated separately. For example, take the left one. To

proceed in a positive direction we must begin at *a* and proceed to *c* by way of *d*. The positive direction for the equivalent source now takes us back through this same route. In going back we find *d c* reversed with respect to the route producing the resultant equivalent E.M.F. between *c* and *a* as *c a*. The student should note again that the sum of the instantaneous values of the actual and equivalent E.M.F.s formed in the complete E.M.F. source circuit is zero. It should also be noted that when *c a* and *a b* are made each to equal *b c* that a three phase source of E.M.F. has been formed. In order that these three E.M.F.s shall be equal, the angles *d c a* and *c a d* must be 60° and 30° respectively.

Since $d a = c a$, $\cos 30° = .866\, c a$, it follows that when a two phase pressure is connected, as in the diagram of Fig. 7, with the proportion of

$$\frac{d a}{c a} = .866,$$

a three phase pressure equal to *c a* will be produced at the terminals *a b c*.

Frequently the three generating circuits in a three phase alternator or motor are connected by what is now known as the Y method. Here again the vector diagram giving the phase position of the three E.M.F.s, resembles the letter Y, after which the method is named. *d a*, *d b* and *d c* are the three E.M.F.s at phase difference of 120°. They are connected as the diagram indicates,—one terminal of each of the three circuits is connected within the armature to a common center. For this purpose similar terminals are chosen. It is evident then that we shall have equivalent E.M.F.s formed between *a b*, *b c* and *c a*. Their values are given by the sides that complete the triangles. Their directions or phase positions are given by the rule laid down above and already frequently applied. Begin at *a* for example, passing through the circuits *d a* and *d c* in a positive direction we find that a positive direction for the equivalent E.M.F., *c a*, is back through *d c* and *d a*, which brings the arrow head for the equivalent pressure *c a* at *a*. In a similar manner the equivalent E.M.F.s *a b* and *b c* are determined as drawn in the diagram. Since the angles *d a b* and *a b d* are each equal to 30°, it follows from simple geometry that

$$\frac{a b}{d a} = \sqrt{3} = 1.73 \text{ and } \frac{d a}{a b} = \frac{1}{\sqrt{3}} = .577.$$

Therefore, when the Y system of connecting a three phase set of E.M.F.s, each E.M.F. of the set will have a value of 57.7% of the resulting line pressure.

ELECTRICAL MACHINERY.

PLATE V.

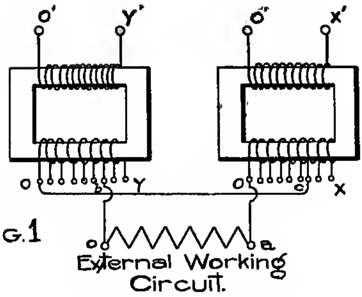


FIG. 1

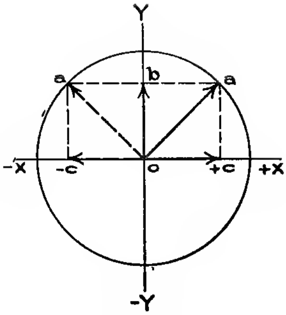


FIG. 2.

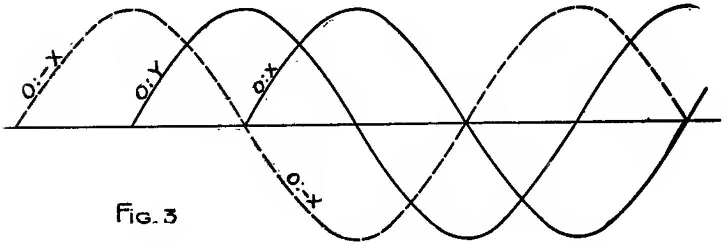


FIG. 3

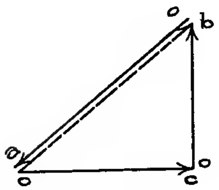


FIG. 4.

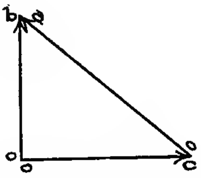


FIG. 5.

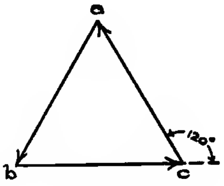


FIG. 6.

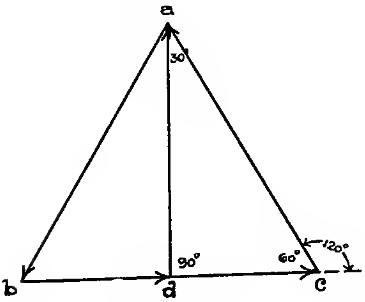


FIG. 7.

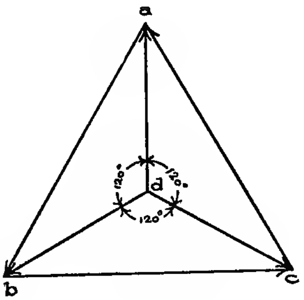


FIG. 8.

THE INCANDESCENT LAMP.

The incandescent lamp is a device for transforming the heat generated by the passage of an electric current through a substance of high resistance, into light. At low temperatures all the power absorbed by the substance passes off as heat, but when a temperature of 350° C. has been attained, a certain percentage of the energy becomes light. The light consumes from five to ten per cent. of all the energy absorbed, the remainder passing off by invisible radiation. The incandescence of the filament in such a lamp is caused by the rapid movement of the particles of carbon, and combustion is prevented by extracting the air from around the hot filament.

A complete lamp consists of the bulb; the filament; the base, which includes the support for the filament; and the connecting wires between the filament and the base. These wires are usually of platinum, for this metal does not shrink away from the glass in which it is sealed, on cooling. Figure 1 shows the various parts of the lamp. *A* is the bulb ready for the filament, *B* the filament and holder, and *C* is the finished lamp. The bulb is of glass and of sufficient size that it will not be unduly heated by the hot filament. The filament is now made only of carbon, though platinum wire was formerly used. Its size is such that it will consume a certain number of watts with the production of the required candle power. The base consists of a core of porcelain or glass on which are mounted two brass pieces which come in contact with the terminals of the circuit when the lamp is placed in its socket.

The manufacture of an incandescent lamp consists of the following processes: (1) Forming the filament; (2) carbonizing the filament; (3) "flashing" the filament; (4) blowing the bulb; (5) mounting the filament in the bulb; (6) exhausting the air from the bulb; (7) testing and rating the lamp.

Filaments are usually made from vegetable fiber which has been changed into a form called amyloid, by treatment in sulfuric acid. The fiber is made uniform in section, by passing it through a series of die plates. This prepared fiber is wound on carbon blocks of a proper form to produce the required shape of loop and the blocks so prepared are carbonized in a carbon box, which is closed, but supplied with vents so that the volatile matter may pass off. This box is gradually raised to a white heat, and after cooling down, the filaments are removed in the form of pure car-

bon, though more or less granular in character. The filaments are now temporarily mounted for electrical connection and are heated by an electric current for some seconds in a hydro-carbon gas, vapor or liquid, which is decomposed by the heat and which deposits carbon on the filament, especially in the hottest parts where it is needed most. This process is known as "flashing" and when the filament is removed from the vessel in which the operation is carried on, it is found to have lost its granular character and to have a smooth, hard and apparently metallic surface, more suitable for the production of incandescence and more durable.

The filament is mounted on its platinum wire supports by means of a carbon paste, which is deposited on the joints. Electroplating and soldering was the method formerly employed. The platinum wires are next sealed into the base of the bulb, which has been made in the meantime as follows: The bulb may be blown either from a piece of glass tubing or directly from the pot. In the latter case the proper form is obtained by blowing in a mold, while in the former case the shape of the globe depends upon the skill of the operator. The air is removed from the bulb finally by means of the Sprengel's or mercury vacuum pump, which is attached to a small piece of tubing left on the tip of the bulb by the blower. After the removal of the air this tip is sealed over.

After the lamp has been mounted in plaster in the base, which consists of a porcelain or glass core, carrying the brass contact pieces, it is tested and rated at the voltage and candle-power at which it has the desired efficiency.

The **candle-power** of a lamp depends on the direction in which it is viewed, for the light given out in any direction will depend upon the luminous area exposed in that direction. Figure 2 shows the variation of candle-power in a flat filament lamp, as different angular positions are occupied by the filament. Twisted filaments are often used to cause a more uniform distribution of light. The real illuminating power of the filament would be the average value in all directions, and this value is called the "mean spherical" candle-power. It is not usual, however, to give this value, for the base cuts off all the light in that direction. The ordinary method is either to rotate the lamp about its own axis while making the measurements, or to take the mean of the measurements when the edge and when the side of the filament is turned toward the photometer.

The **life** of an incandescent lamp means the time that it will

operate before being "burned out." This life will depend upon the quality of the filament and the voltage at which the lamp is operated. The lower the voltage the longer will be the life, and vice versa. Complete tests of a lamp includes measurements of the following quantities: (1) Life; (2) voltage; (3) power consumed; (4) candle power.

When a lamp is new it is much more efficient than when it has been burning for some time, so that, after a time the candle-power will be less if the voltage remains constant, or if the voltage be increased to raise the candle-power to its original value, the power consumed will be greater. This is shown in Figs. 3 and 4. This decrease in efficiency is due to the decomposition of the filament, as a perfect vacuum cannot be obtained. The life is subject to changes in the voltage and will be much less if the voltage be variable. The **useful life** of a lamp is the time taken for its candle-power to fall off 25%. Roughly speaking, the candle-power of a lamp is proportional to the square of the voltage, which shows that a slight increase in the voltage will produce a great change in the candle-power and consequently in the rate of decomposition of the filament.

The so-called **efficiency** of an incandescent lamp is the number of watts used to produce a candle-power. This efficiency will vary in the same lamp, depending on the voltage which is used, and the efficiency then is not really a property of the lamp. For example, if a sixteen candle-power lamp consumed 56 watts at 100 volts it would be, at this voltage, a 3.5 watt lamp. Now if the voltage be increased to 104, 60 watts would be consumed and 20 candle-power produced, making an efficiency of 3 watts per candle-power. A further increase of voltage to 110 would produce a candle-power of 28 and a consumption of power of 78 watts and and the efficiency will rise to 3.5 watts per candle. The efficiency at which it is best to run a lamp is purely a commercial matter, for as the life of the lamp is shorter at a high efficiency, a point will soon be reached at which the cost of renewing the lamps is equal to the saving of power, and this point will be the limit to which the efficiency of a lamp should be increased. High efficiency lamps are also very susceptible to changes in the voltage so that they can never be used on a circuit where this is the case. By a high efficiency lamp is meant one which consumes less than 3 watts per candle-power, while a low efficiency lamp may use from 3 to 4½ watts. Two and one-half watts per candle is the highest efficiency which is found economical at present.

Commercial Features of the Incandescent Lamp. The commercial problem to be settled is the proper efficiency at which lamps should be run and the proper time at which they should be discarded. It is very seldom economical to run a lamp until it burns out, for the efficiency after a time becomes very low. The determination of the proper initial efficiency depends upon the useful life of the lamp at that efficiency. If the saving in power is more than overbalanced by the cost of renewing lamps, evidently the efficiency of the lamp used is too high.

The second important problem is that of the proper time to allow the lamps to burn. Mr. Carl Hering has shown that there is a time at which the lamps should be discarded, and this has been called the "smashing point." The calculations of this point should be made on the basis of the cost of a candle-power of light for a certain time, say 3000 hours. Lieut. M. K. Eyre (*Electrical World*, Vol. XXIII, p. 54) published calculations, from the data of which the following example is worked out :

Problem—To determine the "smashing point" of a lamp under the following conditions. Efficiency and candle-power curves as shown in figures 3 and 4.

Cost of electrical energy, 7 cents per kilo-watt-hour.
Initial efficiency of lamp, 3.2 watts per candle-power.
Cost of lamp, 20 cents each.

There will be a point beyond which the candle-power has dropped to such an extent that the wasted energy more than makes up for the cost of new lamps. Assuming that the lamps run a total period of 3000 hours and assuming different smashing points, the following table has been calculated :

Lamps Smashed at	No. Lamps.	Mean C. P.	Mean Eff.	Total Cost 1 C. P. 3000 Hours.
200 hours	15.	19.7	3.22	83.05 cents
300 "	10.	18.7	3.38	81.7 "
400 "	7.5	17.9	3.54	82.7 "
500 "	6.	17.2	3.64	83.7 "
600 "	5.	16.5	3.83	86.7 "
700 "	4.3	16.0	3.96	88.6 "
800 "	3.75	15.5	4.08	90.7 "
900 "	3.3	15.1	4.18	92.3 "
1000 "	3.	14.7	4.26	93.9 "

Figure 5 is the curve plotted from these values, and this shows that with the conditions assumed, the most economical smashing point is after the lamp has burned 320 hours.

PLATE VI.

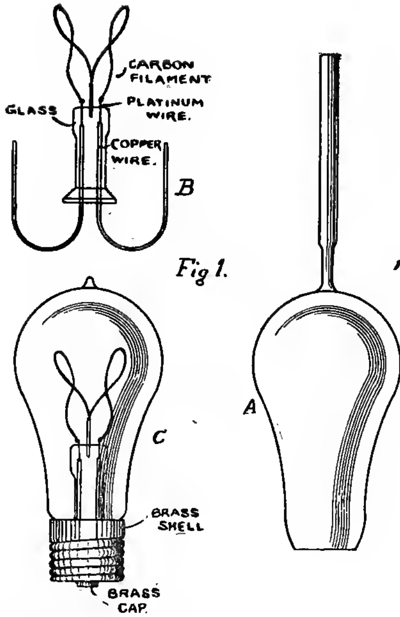


Fig 1.

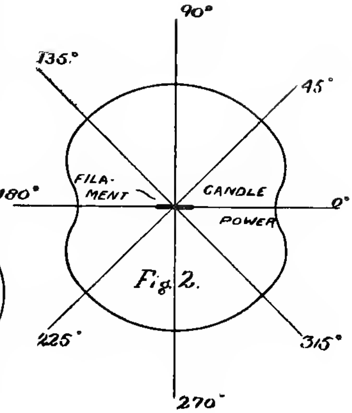


Fig. 2.

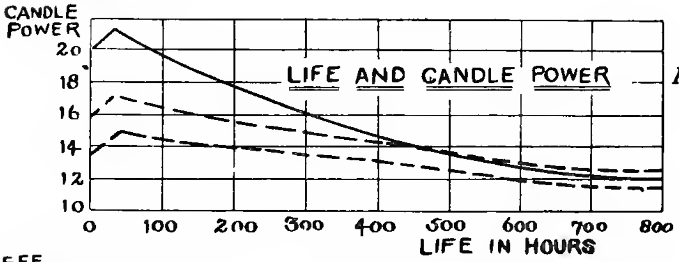


Fig. 3

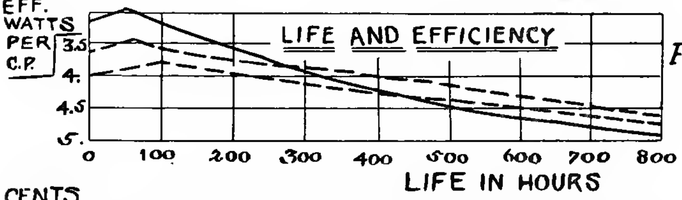


Fig. 4

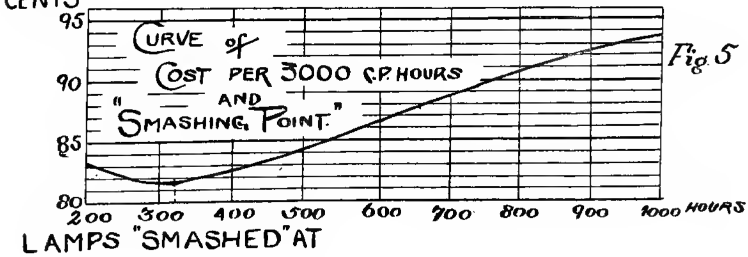


Fig. 5

THE ARC LAMP.

The Arc. The name electric arc, derived from the arched form observed in Davy's horizontal lamp, is given to the stream of incandescent vapor which connects the terminals of an electric circuit, when these are drawn apart and when there is a sufficient electromotive force between them. Any metal or other substance which will form a conducting vapor when heated, will form an arc in this manner. By far the best arc, however, is that produced by carbon, although a larger electromotive force is required. The following table, from Fleming, shows the electromotive forces required to maintain an arc for the substances given :

Material.	*Initiat Volts.*
Carbon . . .	35 volts
Platinum . .	27 "
Iron . .	26 "
Nickel .	26 "
Copper .	23 "
Silver .	15 "
Cadmium . .	10 "

The luminosity of an arc between carbon points is due both to the vapor itself and to the incandescence of the carbon points, which are raised to a white heat, the latter being the most important source of light. Figure 1 represents the appearance of a pair of carbons with the arc between. The positive carbon contains at the end a crater, formed by the rapid volatilization of the material at this point, which is the hottest region about the arc. The temperature of the crater is estimated at from 3500° to 4000° Centigrade, and it emits about 85 per cent. of the total light. The arc itself furnishes perhaps five per cent., while the remainder comes from the tip of the negative carbon. Figures 2 and 3 show the direction in which the light is thrown from the arc. Naturally the crater throws the most of the light downward, if the positive carbon is above, which is the usual practice. Figure 3 is the distribution of the light when the lamp is fed with an alternating current. In this case there is neither positive nor negative carbon and the light is thrown from the smaller crater on each carbon. The position of the crater in a direct current arc can be easily shifted by changing the relative positions of the carbon points. Figure 4 shows such a case, which is intended for lantern use. As the crater is on the side, it acts as a reflector and increases the amount of light thrown out in one direction.

The rating of the candle-power of an arc lamp is usually made

on the basis of its maximum candle-power, and not upon the mean value. For instance, a 2000 candle-power lamp would give at least 2000 candle-power in one direction, but its mean spherical candle-power would not be more than 640 candles. A more satisfactory rating would be on the basis of the watts consumed. The light given out by the crater of an arc lamp is the most intense artificial light producible, being of about one-fourth the intensity of the sun's light, which it closely resembles both in color and in actinic properties. The efficiency of the arc lamp is high, having a value between one-half and one watt per mean spherical candle-power. This means that for a given amount of heat wasted, there is more light produced than in any other form of artificial light, so that in spite of the high temperature of the arc, it gives off less heat than an incandescent lamp of the same candle-power.

The consumption of carbon in an arc lamp is due both to the volatilization of the carbon with the arc thus produced, and to the direct oxidation of the carbon into CO_2, without volatilization. These causes combined produce a consumption of about twice as much carbon at the positive pole as at the negative, which, therefore, wears away but half as fast. The resistance of a 1200 candle-power arc is about five ohms, which is partly real, or "dead" resistance, and partly "spurious," sometimes called the back electromotive force of the arc, due no doubt to its electrolytic character. This spurious resistance plays a large part in the working of the arc. The power consumption of the 1200 candle-power arc is about 500 watts, and two forms are used with either 50 volts and 10 amperes, or 25 volts and 20 amperes. The former relation between voltage and current is now usually employed, as it is easier to transmit a small current than a large one.

The spurious resistance plays an important part in the working of an arc lamp when the arc is long, say over one-sixteenth inch, but in the short arc the dead resistance is more important. The names long and short arcs have been given to these two classes and it might be said that an arc would be considered long when its spurious resistance was more important than the dead resistance. The short arc is very unsatisfactory and is of an unsteady, hissing character, so that it is not in general use. The long arc, which is extensively used, presents the very peculiar phenomena that as the current increases the spurious resistance decreases, so that less volts are required to send a large current than a small one. This has been noted in a previous study in connection

with series dynamos, which are usually worked on the drooping part of their characteristic curves, where the E.M.F. decreases as the current increases. These machines are, therefore, the only ones on which long arcs will work satisfactorily.

All arc lamps consist essentially of a positive and a negative carbon rod, usually round, but sometimes slab shaped, and an electro-mechanism for controlling the relative positions of the carbons.

The carbons are either molded, or "squirted" through a die, the paste being composed of powdered coke or other similar form of carbon, and molasses or some such sticky material, which when baked will be changed to carbon. The "green" rods are then baked at a high temperature until completely transformed into carbon of a uniform consistency and of the required degree of hardness. The carbons are made hard or soft as desired for different purposes, and they are sometimes made with a core of softer carbon, which burns faster than the harder shell and thus keeps the crater and the arc central. In order to lessen the resistance of the carbon, it is frequently plated with copper, which melts and is volatized as it nears the arc, being frequently deposited temporarily in the form of globules on the negative carbon.

The Feeding Mechanism. The function of the electro-magnetic device is to keep the carbons a certain distance apart, and when the current is cut off the carbons must be fed together so that they will be ready to start up again. The elements of this mechanism are shown in figure 5, which embodies the main features of all arc lamps, although the details differ widely. The series coil, C_s, is in the main circuit and it attracts the iron core attached to one end of the lever, l. The shunt coil, C_{sh}, also attracts an iron core attached to the other end of the lever. The purpose of the lever is to work a clutch, C, which controls the motion of the brass rod carrying the positive carbon. The shunt coil is connected around the arc and the series coil, and it is so adjusted that it will overcome the attraction of the series coil for its core when the arc becomes too long and consumes too much electromotive force.

The operation of the mechanism is as follows: Starting with no current in the lamp, the clutch is disconnected from the rod, which is its normal position. When the series coil is excited, the clutch is made to grip the rod and at the same time raise it with the positive carbon. This is what happens when the current is turned

into the lamp. In order to "strike" an arc the carbons must first be in contact and then they must be drawn apart. The distance to which the carbons are drawn apart is determined by the amount of the movement of the lever. The carbons then begin to burn away with a consequent lengthening of the arc, which in a short time becomes too long. At this point the shunt coil is excited to such an extent that its attraction for its core becomes sufficient to overcome that of the series coil. The clutch is disengaged from the rod, which falls under the action of gravity and shortens the arc. As soon as the arc becomes too short the series coil again comes into play and grips the rod and raises it. Between these two forces the arc is maintained at a predetermined length. These movements are so small in extent that no effect on the even working of the arc is noticed. In addition to these coils a short-circuiting device is provided which will cut the lamp out in case it becomes unworkable owing to injury to the coils or to the sticking of the rod, and also a hand switch, *sw*, for cutting the lamp out by hand.

Arc lamps are always run in series so that each lamp may always receive the amount of current for which the coils have been adjusted, a very slight variation in the current throwing the adjustment of the coils completely out.

ELECTRICAL MACHINERY.

PLATE VII.

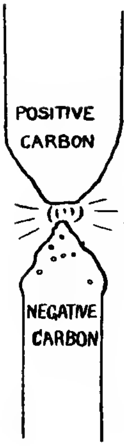


Fig. 1.

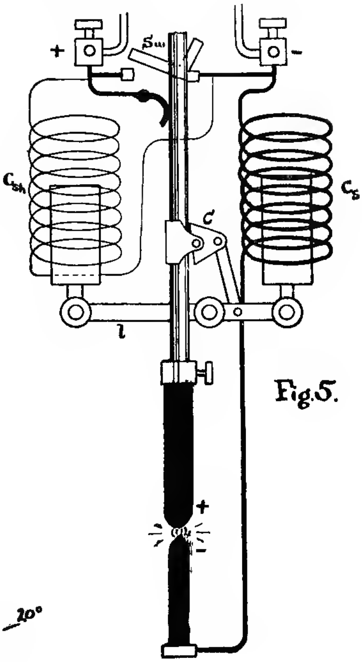


Fig. 5.

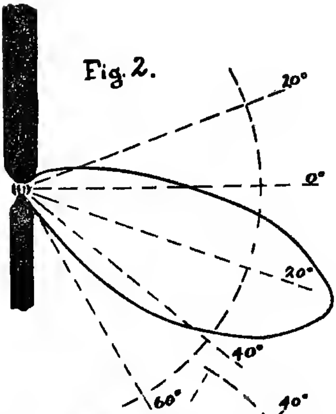


Fig. 2.

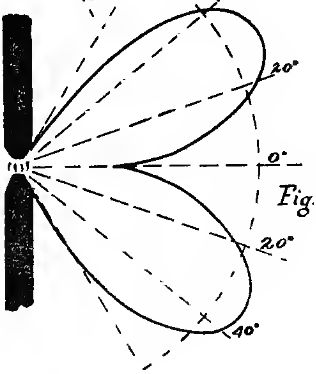


Fig. 3.

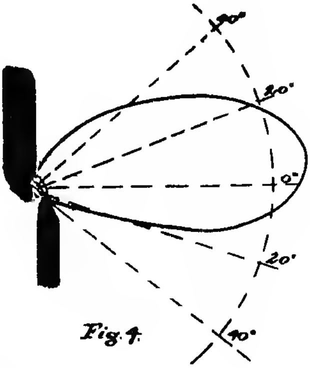


Fig. 4.

SYSTEMS OF DISTRIBUTION.

Transmission lines are used for local and for long distance distribution. Each of these classes requires special arrangement, and in the treatment of local distribution it was seen that the direct current systems were limited in their application to very short distances.

The *transformer* is the device that makes the alternate current the only one for long distance transmission, for the power may be generated at a low pressure and transformed to a high one for transmission. At the point of delivery the pressure may be "stepped down" to any desired voltage and thus utilized. The alternate current does not compete with the direct current for local purposes, for the latter does not involve the cost for transformers.

The alternate current is used in several different forms, *i. e.*, single, two, and three phase, the advantage of the last two being that a greater economy of copper is obtained in the line, and that motors run on these systems are self-starting. There is not a very great difference between the two and three phase systems in their operation, although the three phase requires less copper in the transmission line. On the other hand, the two phase generator is more available for single phase distribution than the three phase dynamo. These conditions give rise to the practice of combining the two systems, using the two phase dynamo for generation and transforming the three phases by the Scott system for transmission. This is the method used in the Niagara plant.

In Plate VIII a scheme of three phase distribution is given as recommended by the General Electric Company. A Pelton water wheel is represented as driving a three phase generator at a comparatively low pressure, say 2000 volts. Each of the three currents then passes through a transformer where its pressure is raised to a high value, say 25,000 volts. The current then passes out into the line which divides, one section being used to run a 3 ph. synchronous rotary transformer, after being transformed again to a lower voltage. The direct current which is taken from the rotary transformer is used in some electrolytic vats. The branch circuit again branches into two sections, in one of which the pressure is lowered to a value suitable for incandescent lamps and passes through meters to record the power consumed, and is then distributed to arc and incandescent lamps and to an induction motor by the regular 2-wire system. The remainder of the current is stepped down to a medium pressure in order to run a 3 ph.

synchronous motor, and then is still further stepped down at each point of demand for light or power. If the load is concentrated near the main line the pressure may be economically stepped down from the maximum value to the minimum by one transformation, and the distribution may be made for one large transformer. If, however, the load is scattered over a large area, the power must be distributed at a reasonably high pressure and be transformed at each point where power is required. On a very short line a low pressure generator might have been used with economy without transformation.

The Two Phase System. This system of distribution is often preferred in practice because of the facility with which the armatures of two ordinary single phase machines may be coupled mechanically so that the pressures they develop will be "in quadrature" or the one pressure will be one quarter period ahead or behind the other. Ordinarily in distributing electric power to two phase motors the line economy is no greater than that afforded by the single phase system. In fact, as a rule, four conductors forming two separate lines are used, each acting in transmission as a single phase line. If, however, a common return line conductor is used for each of the two phase circuits then the current in this middle line conductor will be the vector sum of two equal currents at right angles or $\sqrt{2c^2} = 1.41\,c$. As the size of line conductor is proportional to the amount of current that must be transmitted, it follows that if we designate the size of conductor required to transmit a current of c as a, then to transmit $1.41\,c$ amperes, $1.4\,a$ cir. mils must be the cross section of the middle or two phase common return conductor. The total cross section of conductor for the two phase wire system is $4\,a$ and for the two phase three wire system is therefore $2\,a + 1.4\,a = 3.4\,a$. The two phase three wire system, therefore, uses $\frac{3.4}{4} \times 100. = 85\%$ of the four wire copper. If the loss in the four conductors for the four wire two phase distribution be 4, then 3.4 will be the loss with the three-wire method, with the application of 85% of the copper applied in four conductors. What will be this percentage of copper if the cross section of the conductors is now proportionately diminished until the three conductor equals the four conductor loss, equal amounts of energy being transmitted in each case? Remember that the loss increases inversely as the conductor cross section.

The percentage of four conductor copper required by three conductors will be $85 \times \frac{3.4}{4} = 73\%$. This deduction is more concisely expressed as follows :

Let a be the cross section in cir. mils of the four conductors.
Let a' be the same value for three conductors.
Let 10.5 be the resistance of a mil-foot of conductor.
Let c be the current transmitted for each phase.
Let e be the delivered pressure.
Let w be the delivered watts.
Let l be the transmission distance in feet.

Then for the four wire, two phase system the total line loss equals

$$C^2 R = 4\left(\frac{w}{2e}\right)^2 \frac{\frac{10.5\,l}{a}}{4} \quad \text{and for three wires}$$

$$C^2 R = 3.4\left(\frac{w}{2e}\right)^2 \frac{\frac{1.05\,l}{a'}}{3.4}$$

Equating these $C^2 R$ values we have

$$a' = \frac{3.4^2}{4^2}\,a = 73\% \text{ of } a.$$

This comparison is really not fair to the four wire two-phase system or to other systems in which the pressures between wire and wire on the line are alike. It should be noted in the three wire two phase system that the pressure between the outer wires is the vector sum of the two right angle pressures or $\sqrt{2}\,e$ or $1.41\,e$. If we make the comparison on the basis of having the pressure between the outer wires equal the applied pressure of each phase of the four wire or two circuit method, then the economy of the three wire method greatly suffers and attains the the following value,

$$4\left(\frac{w}{2e}\right)^2 \frac{\frac{10.5\,l}{a}}{4} = 3.4\left(\frac{\frac{w}{2e}}{\sqrt{2}}\right)^2 \frac{\frac{10.5\,l}{a'}}{3.4}$$

$$a' = 1.44\,a.$$

It is evident, therefore, that where the question of insulation enters, the two-phase three wire system could not compete with

the double circuit or single phase system. Ordinarily even for low pressures the double circuit or four wire system is preferred because of its simplicity. It is more or less troublesome in practice to keep track of the middle or odd size of conductor.

The Three Phase System. In fig. 1 the connections are given for transforming a 2000 volt two phase pressure to a 10,000 volt three phase pressure for long distance transmission purposes. In this case the copper economy of the three wire three phase over the four wire two phase, or single phase systems is

$$4\left(\frac{w}{2e}\right)^2 \frac{10.5\,l}{\frac{a}{4}} = 3\left(\frac{\sqrt{3}\,w}{3e}\right)^2 \frac{10.5\,l}{\frac{a'}{3}}$$

$$a' = \tfrac{3}{4}\,a = \text{an economy of } 25\%.$$

The student should note that the ratio of the current in the line conductor to the current in either working circuit *ab*, *bc* or *ca* of fig. 3 is $\sqrt{3}$. This is due to the fact that each line conductor, for example *a*, furnishes a current that divides through *ab* and *ac* in opposite directions as established by the E.M.F.s developed or used in those circuits. The current in *a* is, therefore, the difference of two equal currents 120° apart. Such difference the student will find, by constructing the triangle, will be $\sqrt{3}$ times the value of current in *ab*, *bc* or *ca*. It should also be noted that in the three phase system the pressures between wire and wire in all instances are the same, so that the gain in copper of 25% is genuine for all instances.

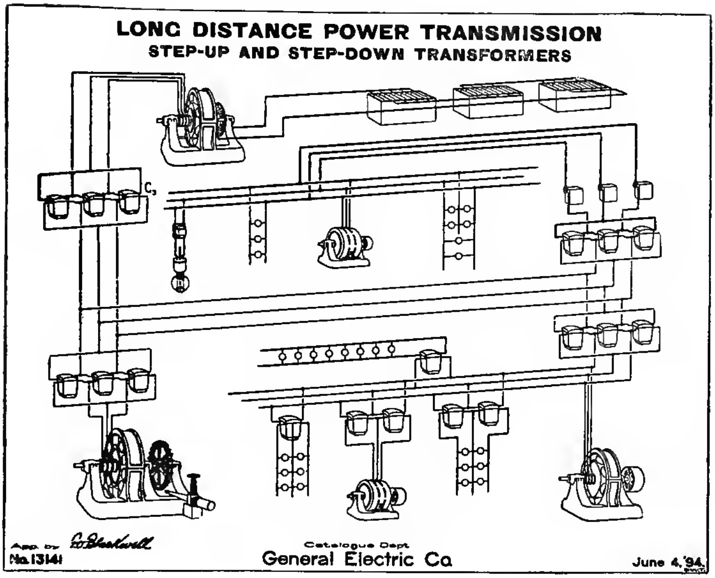
It is also a fact that a three phase line will develop, when transmitting a given amount of power at a given pressure, less reactance E.M.F. due to inductance, than a two phase or single phase line. For these reasons the three phase line is much preferred for long distance transmission of power.

The Monocyclic System is used where local distribution of light and power current is to be effected within a territory covered by a radius of a few miles. Where much incandescent lighting is to be done, the single phase 1000 or 2000 volt alternate current transformer system is much preferred in practice because of its simplicity. There is, however, a demand for facilities to operate numerous small stationary motors from incandescent lighting circuits. These motors vary in size from ⅛ to 50 or 100 horse-power. A service of this character is best made by means

of the monocyclic system of generating and distributing electrical energy. The circuits of the generator for this system are given in the diagram of Fig. 4. There is a main alternator coil developing a single phase pressure of 2080 volts. Should the entire output of the alternator be used for incandescent lighting, this coil would furnish such output in single phase current as in the single phase system of distribution.

For furnishing power current to induction motors an additional generating coil is provided. This is called the "teaser" coil. It generates a pressure at right angles to the main coil, at the middle of which one end of the teaser coil is connected, while the other end is taken to a collector ring. For power purposes then the main circuit and the teaser terminal by line conductors are run to the motor locality. There two transformers are used to change the special two phase or monocyclic source into three phases of properly reduced pressure. The diagrams of connections and of values applied respectively, are given in Figs. 6 and 7. As the teaser coil needs to have but one-quarter the capacity of the main coil, it follows that the cost of the generator is but little in excess of one in which it is entirely omitted. A monocyclic generator may profitably, therefore, be installed, even where the amount of power current business will be small or uncertain.

PLATE VIII.


LONG DISTANCE POWER TRANSMISSION
STEP-UP AND STEP-DOWN TRANSFORMERS

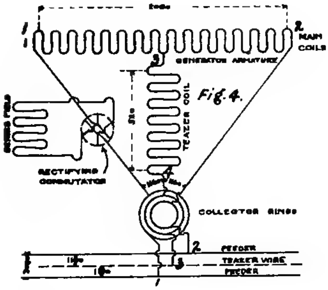


Fig. 4.

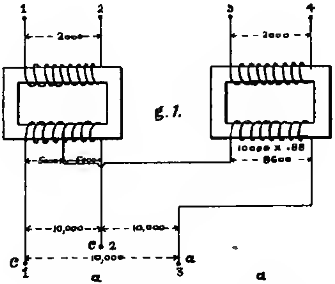


Fig. 1.

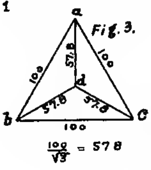


Fig. 3.

$$\frac{100}{\sqrt{3}} = 57.8$$

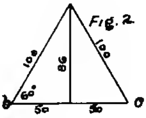


Fig. 2.

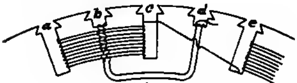


Fig. 5

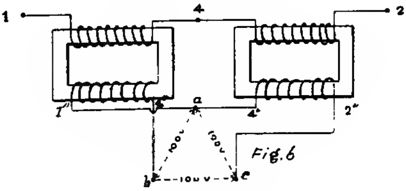


Fig. 6

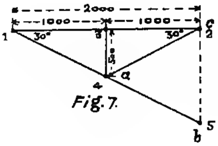


Fig. 7.

COMMERCIAL ELECTROLYSIS.

Electrolysis is the name given to chemical decomposition produced by the electric current. When a current of electricity is passed through a liquid, decomposition of the latter usually occurs and this may be apparent in the following ways :

(1) by a resolution of the liquid into its gaseous components,
(2) by a deposition of the base of the salt in soluion,
(3) by chemical changes in the electrodes.

Of the first class of electrolytic phenomena, practical applications are made in the manufacture of gases, such as hydrogen, oxygen, chlorine, etc.

The second class furnishes a method for the commercial production and refinement of various metals, among which the important ones are silver, copper and aluminum. In the cases of silver and copper the metals are deposited from a solution of the metals in an acid, while aluminum is deposited electrolytically from a fused salt, the action being the same in both cases. Both of these classes furnish accurate methods for determining the strength of an electric current, for the amount of chemical action is always directly proportional to the current, other conditions being the same.

A very important application of electrolysis is that included under the third class, namely, the electric accumulator, which has been partly discussed. No electricity is stored in this device, but the energy of the electric current is changed into potential energy in the electrolysis of the chemicals which go to form the cell, and this energy may be restored to the circuit by allowing the chemicals to act upon each other as in the primary cell, with a production of an electro-motive force.

Copper Electrolysis. In the mining of copper a number of impurities are found in the ore which cannot be removed by roasting and smelting. Electrolysis offers an easy means for separating the copper, silver and impurities from each other, and the metals are obtained in a pure state. The copper after smelting is cast into large ingots, which after being surrounded with heavy bagging are placed in a solution of copper sulfate, nearly saturated, and a large electric current is sent through the liquid from the in-

got to a plate of copper which forms the other terminal of the bath. The copper is dissolved from the impure ingot and is deposited on the plate in a pure state. The electrode or terminal which is dissolved by the current is known as the anode, the other being the kathode, while the intervening liquid is the electrolyte. As only copper is dissolved from the anode, any other metals present in the ingot will be left behind in the bagging and may be redissolved and electrolyzed for the silver or other metal in a separate bath. After the pure copper has been deposited in this manner it is remelted and is cast into ingots of the proper size for rolling into sheets and bars, or drawing into wire. The copper obtained in this manner is finer than the best copper obtained in any other manner and ordinary copper is now about as fine as the standard samples used by the physicist Matthieson when he made his famous determinations of the specific resistances of metals. For this reason copper is sometimes spoken of as 102% fine. A current of one ampere will liberate .0003307 grams of copper per second, or in other words this quantity is deposited per coulomb of electricity passing, and this constant is called the electrochemical equivalent of this metal.

Aluminum Electrolysis. The commercial production of aluminum is an important electrolytic process. This metal cannot be smelted from its ores, which are very common, as these are very refractory. The oxide of aluminum, known as alumina, (Al_2O_3), is the source of the metal. This alumina is formed from Bauxite which is found in some of the southern states and it is prepared as follows: The ore is crushed in a stamp mill and treated with sodium hydroxide and the aluminum is thus dissolved. The insoluble residue is discarded and the carbon dioxid is forced through the sodium aluminate, forming sodium carbonate and precipitating aluminum oxide, which after washing and drying is shipped to the smelting works in the form of a white powder.

The alumina is placed in a carbon lined iron box, in which a bath of fused cryolite is kept liquid by the heat due to the resistance offered to the flow of a current which passes through the box from large carbon rods in the center to the carbon lining. When the alumina is thrown into the bath it is reduced at the negative terminal, or lining, and the high temperature of the bath keeps the reduced metal in a molten state. It is removed from this box in a practically pure state.

Aluminum has a number of uses in the arts, principally in con-

nection with other metals in the form of alloys, which possess peculiar properties. For example aluminum bronze is one of the hardest metallic substances with the exception of some of the rare metals.

Electrolysis of Pipes. An unfortunate application of electrolysis is found in the effect of the stray current from the return rails of electric street railway lines. Naturally the current takes the easiest path to return to the generator and this is often found in metal pipes which run in the same general direction as the rails.

To produce electrolytic action it is necessary to have an anode, a kathode and an electrolyte and these conditions are met in the above case by the pipes, the rails and the chemicals present in the moist soil. The loss of metal occurs where the current leaves the pipes so that if they are positive with respect to the rails they will be eaten away. Five grains per ampere-hour is an average value of the consumption of the anode, the exact amount depending on the minerals present in the soil, chlorides, nitrates and sulfates being the most active in the order named.

Two methods for the prevention of this trouble are possible: either by keeping the current away from the pipes, or by making them a part of the return circuit. The first could only be done by coating the pipes with an insulating substance, which would be a troublesome arrangement. The second method is the one in use and the pipes are connected in such a manner that the current neither enters or leaves them except through a joint of low electrical resistance. If the pipes are kept at the same or at a lower potential than the rails there will be no injurious effect on them, for no decomposition takes place where the current enters a metal.

THE TRANSMISSION OF INTELLIGENCE.

Two classes of electrical apparatus will be considered under this head, the telegraph and the telephone.

The original telegraph instrument, as its name indicates, was intended to write at a distance, and this was accomplished by means of the attraction of an electro-magnet for its keeper or armature when excited by an electric current. The movement of the armature was used to operate a stylus, which either wrote upon a ribbon of paper or indented it, the paper meanwhile being fed through the apparatus by suitable clock-work. These machines are still used to a slight extent, but they have been replaced for land use by the " sounder," which simply makes a series of clicks instead of writing. . The name telegraph is not strictly accurate, but it still clings to the apparatus.

The following parts comprise a telegraph system : (1) the sending apparatus ; (2) the transmitting devices ; and (3) the receiving apparatus.

The sending end of the line requires only a key or switch which will make and break the circuit as desired. The ordinary key or lever key, as shown in figure 1, makes contact at the point *c* on being depressed and thus completes the circuit through the line. A short-circuiting switch *sw*, is closed when the instrument is not in use, so that the circuit is complete for the other operators. In automatic and rapid telegraphy, which is not used much in this country, the contact is made through perforations in a strip of paper. Holes are punched in the strip by the operator and when this strip is fed through the sending machine, a metallic contact, which rests on the strip, passes through the perforations and completes the circuit and thus sends an impulse through the line. This machine is capable of very high speeds.

Transmission. A battery of primary cells is needed to supply the current for these instruments and as the circuit is to be closed nearly all the time, a cell is needed which will not " polarize " when the current flows. The blue-stone or gravity cell answers these conditions, for it works best when kept on a closed circuit, hence its name, closed-circuit cell. A single wire is used to transmit the current for a telegraph line, and all the instruments are

connected in series. The ground is used for the return circuit and but one operator can use the line at a time in the usual system. On long lines an excessive battery power would be required if but a single battery were used, for the resistance of the line is high and each instrument requires a considerable current. As the resistance of each instrument is considerable, and as they are connected in series, a high voltage would be required to send a current through them. In order to economize wire in the line and to make the operation more satisfactory, the separate instruments are worked through relays. The relay (see Fig. 3), consists of an electro-magnet with an armature adjusted to move when a very slight current is sent through it. This armature then acts as a key and completes the local circuit when it is attracted to its core. The local circuit contains a small auxiliary battery of one or more cells and the sounder, or other receiving instrument. By this relay system the large battery on the line is done away with, and on account of the smaller current required a much smaller wire may be used.

The receiving apparatus consists usually of a sounder, as in figure 2, but it may be a writing or printing device known as a recorder. The sounder is made to click with one sound on being attracted, and with another when it is released, so that the time which elapses between these two sounds is a measure of the time during which the sending key has been held down. This interval makes the distinction been the dots and dashes. The armature sometimes carries a stylus which marks the dots and dashes, while in the apparatus used on cables, the current deflects the moving coil of a galvanometer to which is attached a capillary tube, which traces a sinuous line on a paper ribbon. The sending key in this case is double, one key sending the current in one direction. while the other sends it in the opposite direction. The galvanometer coil is thus deflected either to one side of the zero position or the other, according to the direction of the current. The fact that the capillary tube is usually made in the form of a syphon, the upper end dipping into a vessel of ink, gives the name *syphon recorder* to this instrument.

The Morse Alphabet. As the only available motion in the Morse apparatus is such as to produce clicks on the sounder or indentations in a strip of paper in the recorder, the alphabet must be arranged according to the time which the armature carrying the sounder arm or recorder stylus remains in contact with the

core. This leads to the use of two signals, a dot and a dash which is three times as long. Another and still longer dash is used for one letter (1). The alphabet is changed slightly to suit the syphon recorder, and a twitch of the capillary tube in one direction (above the center line) represents a dot and one in the opposite direction a dash. In case of such long cables that the current is too weak to operate the syphon recorder, a reflecting galvanometer is used and a spot of light is allowed to be thrown upon a screen, and by this means the twitchings of the needle are observed.

The Duplex System. As the erection and maintenance of a long line is a considerable expense, various devices are used in order to make the line as efficient as possible. One plan already mentioned was to send the messages very rapidly by a special machine. Another plan is to send more than one message at a time on the same wire. Of the various plans for doing this the simplest one will be described. This system can be applied to the quadruplex system also, but this becomes quite complicated. Figure 4 shows the connections for one duplex system. The sounders, S_1 and S_2 are each wound with two coils in opposite directions, or differentially. One of these coils on each instrument is connected in series with the line, the keys, K_1 and K_2, the batteries, B_1 and B_2, and the earth. So far these are the usual connections. The back contact of each key is connected to the second coil of the sounder through the resistances, R_1 and R_2, each of which is equal to that of the line plus one-half of the sounder coil. If both operators wish to use the line at the same time they will depress their keys and block the line, for the batteries will oppose each other. The local circuit of each station will, however, be complete through the resistances and the sounders which will both click just as though the currents had passed each other on the wire. Suppose that but one operator wishes to use the line, on depressing his key the current will divide in his sounder, the two parts going around the magnet in opposite directions so that there will be no effect. On the other end the current will go to earth through one-half the sounder coil and this will be operated. In this way the one wire will give the same results as if two had been used.

The Telephone. The classification of apparatus is the same in this case as before. The sending apparatus consists of (1) the microphone; (2) the induction coil; (3) the battery; (4) the call bell. The transmission takes place through a pair of wires, for a ground return is never satisfactory. At the receiving end the receiver or telephone proper changes the electrical oscillations into sound again.

The first apparatus used by Bell for transmitting sound consisted of a diaphragm of thin iron mounted near the end of the bar magnet, which was surrounded by a coil of fine wire as in figure 5. When the diaphragm was set in motion by the vibrations of the air which go to make up the sound, it changed the reluctance of the magnetic circuit of the bar. The induction in the magnet was thus altered and an electro-motive force was set up in the coil surrounding the bar. By connecting a similar apparatus at the other end of the line, the coils of wire being in series, the alternate weakening and strengthening of the magnetism of the bar by the current surrounding it caused vibrations in the second diaphragm similar to those in the first. This device is still used for the receiver.

In this case the amplitude of the vibrations in the receiver were very much smaller than those in the transmitter, on account of the losses in transformation and transmission, so that, except for short distances the sounds were barely audible. An amplifying device was necessary and this led to the invention of the microphone by Hughes and others.

The microphone depends for its working upon the variable resistance of carbon contacts when subject to varying pressures. (See figure 6.) An electric current meets less resistance when the contacts are under greater pressure. By so placing one or more carbon contacts in an electric circuit so that the resistance of the joint would be disturbed by the vibrations of the air, a device was obtained in which the electric current in the circuit bore some relation to the amplitude of the sound wave. Two forms of microphone are common: one in which the jar produced by the sound varies the contact, and one in which the carbon is in contact with a vibrating disc by which the actual pressure on the carbon contact is varied. This latter is the most successful form for transmitting speech.

A telephone when placed in series with a battery cell and such a microphone, will be effected by the varying current which flows

through the circuit. The effect on the telephone will, however, be greatly amplified if the microphone be connected in series with the primary circuit of an induction coil the secondary of which is connected to the telephone. (See I, figure 8.) As the secondary circuit contains a much greater number of turns than the primary, the electromotive force is raised and the telephone coil can be wound with many turns of fine wire, and a large magneto-motive force will be thus obtained.

The microphone is made in various ways, but the underlying principle is that the vibrations of the diaphragm shall vary the pressure between one or more carbon contacts. This carbon is sometimes in the form of rough buttons, and in other cases it is powdered.

The resistance of a telephone circuit is ordinarily high so that the ordinary call bell cannot be used to send signals over the line. This work is done by means of the magneto generator and bell. A pair of bobbins is rotated by means of suitable gearing in front of the poles of a powerful permanent steel magnet. (See G, figure 8.) There is thus generated in the bobbins an alternating current. The current is received in an electro-magnetic bell as is shown in figure 7. The magnets and the armature are kept polarized by the permanent magnet *NS*. The windings on the magnet are so arranged that when the current flows in one direction it weakens one magnet and strengthens the other and the armature is attracted to the strongest core. This operation is reversed for every period of the current, and the hammer *h* vibrates in unison with the current. These magneto bells are made to ring through as great a resistance as 30,000 ohms, if required, but they are usually wound for 10,000 ohms, and they form a convenient apparatus for many kinds of electrical testing.

An important feature in a telephone set is the switch for connecting the various parts in circuit at the proper time. The call bell must be in circuit when the telephone is not in use, and it must be cut out when the telephone is being operated. The diagram shows the arrangement of the various parts.

The current enters by the line which is connected to the lightning arrester and short circuiting plug *A*. Wire *No. 1* then passes to the hinge of the switch *S*, by which the current is transferred to the bell or the receiver. The weight of the receiver holds the switch down when hung upon it, but when the receiver is removed the spring draws the blade of the switch into contact

with the upper jaws. When the switch is down it is in contact with jaw *No. 3* which is connected to the magneto machine, but as this is short-circuited by the switch *sp*, the current passes through it to the bell and thence to the line.

When the main switch is up, contact *No. 2* connects the microphone *M* in series with the battery *B*, and the primary of the induction coil *I*. It also connects the receiver in series with the secondary of the induction coil, and with the line so that the arrangement is complete both for sending a message and receiving one. The only remaining connection to be noted is that in the magneto machine As the self-induction of the armature coils is high they must be thrown out of circuit except when the machine is being used to ring the bell on the other end of the line. It is cut out of circuit by the short-circuiting switch. The handle and armature are movable in and out, being normally kept short-circuited by the spring *sp*. When the machine is to be used the handle is pressed in, the armature disconnecting from the switch *sp* and it is then in the main circuit. Releasing the handle allows the armature to come back to its normal short-circuited position.

ELECTRICAL MACHINERY.

PLATE IX.

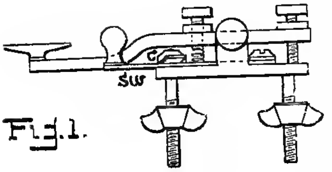
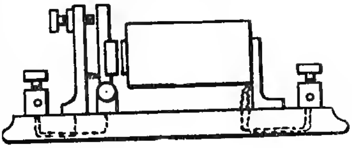


Fig.1.

Fig 3.



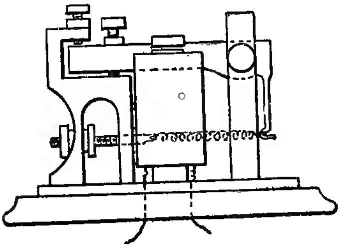


Fig.2.

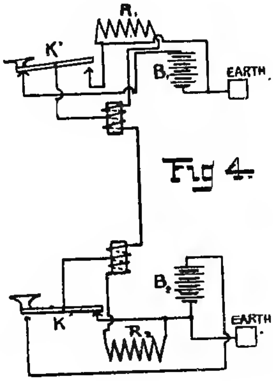
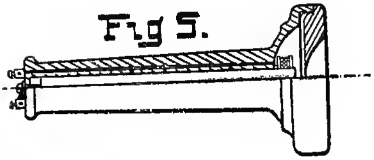


Fig 4.

Fig 5.



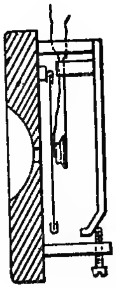


Fig.6.

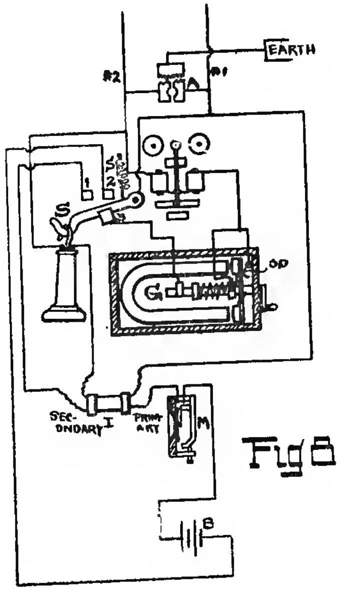


Fig 8.

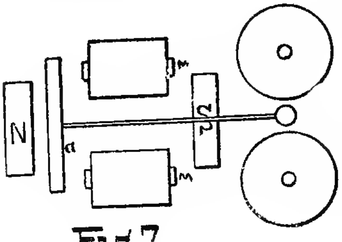


Fig.7.

ABSTRACTS FROM THE UNDERWRITERS' RULES.

The fire insurance companies, through their board of underwritters, lay down certain rules for the guidance of parties installing electrical apparatus in insured buildings. All electrical work done is subject to the inspection of the insurance companies and their rules cover mainly methods of wiring and of mounting apparatus.

Installations are divided into the following classes:

A. Central Stations for light and power.
B. High Potential Systems. Over 300 volts.
C. Low Potential Systems. 300 volts or less.
D. Alternating Systems. Convertors or transformers.
E. Electric Railways.
F. Electric Heaters.
G. Storage or Primary Batteries and Miscellaneous.

Class A.

Generators must be located in a dry place and the frame must either be insulated or grounded. They must not be placed in rooms containing hazardous material and must be covered when not in use. No oily waste is allowed except in *approved* metal cans. (The word *approved* means inspected and passed by the underwriters.) A competent attendant must be present where generators are running.

Conductors must be in sight and readily accessible; on non-combustible insulators: separated from floors, partitions, etc.; kept rigidly apart; covered with non-inflamable insulation; and of the capacity specified on page 28.

Switchboards must be placed so as to reduce fire risks; accessible from all sides if the wiring is on the back; free from moisture and of non-combustible material.

Resistance Boxes and Equalizers must be equipped with non-combustible frames and mounted on switchboards or separated from conbustible material.

Lightning Arresters must be attached to each side of every overhead circuit connected with the station and mounted as above. Each lightning arrester is to be provided with at least two "earths." An arc must not be maintained after the discharge has passed.

Testing.—All circuits are to be tested for "grounds" every two hours, low potential systems being provided with "ground detectors." Copies of tests are to be preserved.

Motors are installed in a manner similar to generators except that they must always be insulated from the floor or ceiling and under peculiar circumstances must be placed in fire-proof cases.

Class B.

Outside Conductors must be well insulated and tied with wire of equal insulation to insulated supports consisting of glass or porcelain insulators made to throw off moisture. Moisture must not be able to form a short-circuit between the wires and at places where accidental contact with other wires might occur, "dead" guard wires must be used. Joints are to be first made mechanically and electrically perfect and then soldered. Telegraph, telephone and similar wires are not to be placed on the same cross arms as electric light and power wires.

Service blocks must be covered over their entire surface with at least two coats of insulating paint.

Interior conductors must be insulated extra where they enter buildings, passing through non-combustible and water-proof tubes, and they must be provided with drip loops outside. The wires must pass through a "double-pole" switch on entering the building, so-called "snap" switches not being allowed. The insulation and splices are the same as before. The distance between wires is to be eight inches, except on hanger boards, etc., and wires must be electrically separated from walls, etc., by non-combustible tubing and from mechanical injury by boxing where necessary.

Arc lamps and other devices must be carefully isolated from inflammable material, and the arc is to be surrounded by an unbroken glass globe. A hand switch is to be provided for shunting the current around the arc in case of accident to the latter. Wire netting must surround the globe and sparks must be arrested at the top of the globe. Hanger boards are to be in plain sight and if they are not used the lamps must not be hung by the conductors.

Incandescent lamps in series must have automatic cut-outs, and each lamp is to be supported from a hanger-board by means of rigid tubing. No electro-magnetic switches can be used, and no series lamps can be attached to gas fixtures.

Class C.

Outside Overhead Conductors must be erected as for high potential systems, but must have an approved fusible cut-out near the entrance to a building.

Underground Conductors similar to above.

Inside wiring is installed similar to high potential wiring, except that the wires may approach each other within 2½ inches for 150 volts or less, and proportional distances for greater pressures.

Interior conduits, consisting of insulating compound sheeted with metal, may be used either in walls or exposed. The tubing must be continuous from junction-box to junction-box.

Double-pole safety cut-outs must be placed at every point where there is a change in the size of wire, (unless the cut-out in the larger wire will protect the smaller). The fusible strip must be enclosed. No set of lamps requiring more than six amperes shall be dependent upon one cut-out.

Safety fuses must be marked with the greatest number of amperes which they will carry indefinitely without melting. The fusible strips must have contact tips of harder metal. They must be so proportioned that they will melt before the safe carrying capacity of the circuit in which they are connected shall have been exceeded.

Switches besides being on non-combustible bases and in accessible places must be so located that gravity will tend to open rather than to close them.

Except in flexible cords and gas fixtures no size of wire smaller than No. 14 B. & S., is allowed.

Class D.

Convertors must not be placed inside of buildings unless absolutely necessary, in which case they must be located as near the entering point of the primary wires as possible and in a fire-proof enclosure. They must not be placed in any but metallic or other non-combustible cases. They must not be attached to the walls of buildings, except they are separated therefrom by substantial insulating supports.

Primary conductors must be insulated well and protected from mechanical injury, and in the building must be furnished with a switch and a fusible cut-out, which are preferably outside the building. The wires must be at least ten inches apart and at the same distance from all conducting bodies within the building.

Secondary conductors are installed as under low potential systems.

Class E.

This class of work should be installed as far as possible like arc circuits.

Power stations shall be provided with an automatic circuit breaker on each circuit, on a fire proof base and in full view of the attendant.

Trolley wires must not be smaller than No. 0, B & S copper or No. 4, B & S silicon bronze. They must be well insulated and capable of being disconnected from the power station. This rule also applies to feeders.

Lighting and Power from railway wires must not be permitted, under any pretense, in the same circuit with trolley wires with a ground return, nor shall the same dynamo be used for both purposes, except in street railway cars, electric car houses and their power stations.

Power house wiring must be installed as in class *B*. Must have the rails bonded at each joint with not less than No. 2 B & S annealed copper wire; also a supplementary wire to be run for each track.

Ground return wires, when used must be so arranged that no difference of potential will exist greater than 5 volts to 50 feet, of 50 volts to the mile between any two points in the earth or pipe buried therein.

Class F.

Electric heaters must be treated as stoves. Must have double-pole inducating switches and cut-outs. Flexible conductors for portable apparatus must be insulated so as not to be injured by heat.

Class G.

The wiring is the same as for similar apparatus fed from generators. All secondary batteries must be mounted on approved insulators. Insulation must be provided as in cases where acid fumes exist, which come under the head of hazardous materials.

Miscellaneous. The following are the approved non-combustible, non-absorbing, insulating materials :—Glass; Marble (filled) ; Slate without metal veins ; Porcelain, thoroughly glazed and vitrified ; Pure sheet mica ; Lava (certain kinds of) ; Alberene Stone.

NOTE—For complete information see the small hand-book published for the Underwriters' National Electric Association.

ERRATA.

Page 2, line 11, for "current" read "circuit".

" 20, " 12, " "line" " "wire".

" 29, " 3, " "figure 4" " "figure 3".

" 41, " 9, " "1 and 3" " "2 and 4".

" 42, " 9, after "180°" insert "behind".

" 42, " 18, for "of" read "to".

" 49, under figure for "Fig. 8" read "Fig. 9".

" 50, line 17, for "Fig. 8" read "Fig. 9"

" 53, " 27, for "*o, ob, oc,*" read "*o of oc*".

" 54, " 22, " "ac" read "oc".

" 59, " 31, " "3.5" read "2.7".

" 62, " 27, " "25 volts" read "40 volts".

The 20 ampere lamp, therefore, requires 800 watts.

Page 41, Figure 1, coils 3 and 4 should be wound in the opposite direction.